FAO
FISHERIES
TECHNICAL
PAPER

449

ISSN 0429-9345

Geographic information systems in fisheries management and planning

Technical manual

FAO
FISH
TECH
PAP
no.449

LIBRARY
Pacific Islands Fisheries Science Center
National Marine Fisheries Service
2570 Dole St
Honolulu, HI 96822-2396

Cover graphic: Emanuela D'Antoni

Copies of FAO publications can be requested from:

SALES AND MARKETING GROUP
Information Division
Food and Agriculture Organization of the United Nations
Viale delle Terme di Caracalla
00100 Rome, Italy

E-mail: publications-sales@fao.org
Fax: (+39) 06 57053360
Web site: http://www.fao.org

NMFS Honolulu Library

Geographic information systems in fisheries management and planning

FAO FISHERIES TECHNICAL PAPER 449

Technical manual

by
Gertjan de Graaf
Nefisco Foundation
Amsterdam, the Netherlands
Felix Marttin and **José Aguilar-Manjarrez**
Inland Water Resources and Aquaculture Service
FAO Fisheries Department, Rome, Italy
and
Jeff Jenness
Jenness Enterprises, GIS Analysis and Application Design
Flagstaff, Arizona, USA

LIBRARY
Pacific Islands Fisheries Science Center
National Marine Fisheries Service
2570 Dole St.
Honolulu, HI 96822-2396

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
Rome, 2003

The designations employed and the presentation of material in this information product do not imply the expression of any opinion whatsoever on the part of the Food and Agriculture Organization of the United Nations concerning the legal or development status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

LIBRARY
Pacific Islands Fisheries Science Center
National Marine Fisheries Service
2570 Dole St
Honolulu, HI 96822-2396

ISBN 92-5-104999-8

All rights reserved. Reproduction and dissemination of material in this information product for educational or other non-commercial purposes are authorized without any prior written permission from the copyright holders provided the source is fully acknowledged. Reproduction of material in this information product for resale or other commercial purposes is prohibited without written permission of the copyright holders. Applications for such permission should be addressed to:
Chief
Publishing Management Service
Information Division
FAO
Viale delle Terme di Caracalla, 00100 Rome, Italy
or by e-mail to:
copyright@fao.org

© FAO 2003

PREPARATION OF THIS DOCUMENT

The FAO Inland Water Resources and Aquaculture Service (FIRI) has been active in promoting the use of Geographic Information Systems (GIS) and remote sensing since 1985. However, a manual to use along with GIS software for the fisheries biologists in the field, explaining the use of GIS in inland fisheries management in a way that is understandable to non-GIS users, had not been produced at FIRI until now.

While preparing the present manual our research led us to conclude that the potential for GIS to contribute to fisheries management in developing countries is quite large and that there is a substantial demand for educational material relating to its understanding and application. For these reasons we feel that this manual is unique, appropriate and timely. We hope this manual will help boost the use of GIS in fisheries management and planning, and will help foster the sustainable use of natural resources.

ABSTRACT

Many fishery biologists and policy makers involved in inland fisheries management and planning are unaware of GIS technology and its potential for fisheries planning and management. The FAO Inland Water Resources and Aquaculture Service (FIRI) has been active for the last 19 years in promoting the use of GIS and remote sensing in fisheries and aquaculture. Promotional activities have been carried out through training, projects, field missions, and oral presentations and publications. However, a manual to use along with GIS software for the fisheries biologists in the field explaining GIS in a way that is understandable to non-GIS users had not been produced until now. This manual was written to overcome this knowledge-gap, it is a "do-it-yourself" manual giving a short introduction to GIS software and its applications in fishery science.

The overall objective of this manual is to encourage fishery managers to use this tool (GIS) to foster the sustainable use of natural resources. The manual is aimed at fisheries biologists, aquatic resource managers and decision makers in developing countries who have no knowledge about GIS. The manual was written for use with ESRI's ArcView 3.x and Spatial Analyst software.

There are five main sections in the manual:

- GIS concepts and functions and key tools provided by ArcView 3.x,
- Geographic coordinate system and map projections,
- Raster data and analysis,
- Regression analysis, and
- Application case studies.

All sections are accompanied by exercises that have been designed to illustrate key applications of GIS in inland and marine fisheries management. Also, a custom-designed ArcView grid regression extension is included to show the integration of GIS with surplus production models.

At the end of the training with this manual, the reader should be able to: apply learned principles and GIS to their own professional situation, perform analyses on their own data, be aware of the vast possibilities that GIS can provide and be able to communicate with GIS expert counterparts.

The manual is useful for a broad range of fishery applications. However, this manual by no means covers all possibilities of GIS, it merely touches upon some of the most important features for fisheries management and planning.

FAO. 2003. *Geographic Information Systems in fisheries management and planning. Technical manual*, by G. de Graaf, F.J.B. Marttin, J. Aguilar-Manjarrez & J. Jenness. FAO Fisheries Technical Paper No. 449. Rome. 162p.

Distribution:
FAO Members and associate members
FAO Fisheries Department
FAO Fisheries officers in FAO Regional and Subregional Offices

CONTENTS

Preparation of this document iii
Abstract iv
List of Figures viii
List of Tables xiv
Acknowledgements xv
Abbreviations xvi

1. Introduction 1
1.1 GIS and remote sensing activities at the Inland Water Resources and Aquaculture Service (FIRI) 2
1.1.1 Past activities at FIRI from 1985 to 1999 2
1.1.2 Current activities 2

2 Training with the manual 4
2.1 Set up of the training and the manual 4

3 What is GIS? 6

4 Starting ArcView 8
4.1 Starting ArcView and Adding a Theme 9
4.2 Opening an ArcView Project 10
4.3 What is an ArcView project 11

5 Some Tools in View 12

6 Graphical displays in the Map View 15
6.1 Changing colours of a legend 15
6.2 Changing the number of classes in a legend 15
6.3 Changing the values of the classes 16
6.4 Saving and Loading of legends 17
6.5 Selecting and applying bar or pie graphs 17
6.6 Displaying two parameters in one Theme 19
6.6.1 Riverine frame survey of Pais Pesca 21

7 Views and Themes: definitions and characteristics 22

8 Joining data with location on a map 23
8.1 Joining a table with a polygon file 24
8.2 Joining fish catch data of the districts with a polygon shape file 28

9 How to edit your Theme table and do calculations 31
9.1 Adding a field and making calculations in a table 31

10 Difference between Polygons and Points 34
10.1 Difference between polygon and point shapefiles 34

11 Points and degrees 35
11.1 The geographic coordinate system 35
11.1.1 Working with latitude - longitude 35
11.2 Putting field data into a GIS 36
11.3 Calculation using collected field data 39
11.4 Graphical displays of points 39

12 Projection 40
12.1 Map projection 40
12.2 Changing projections 40
12.2.1 Different projections 41

13 Raster data 45
13.1 Overlay 46
13.2 How to set your defaults for the use of Spatial Analyst and change the working directory 47
13.2.1 Settings of Spatial Analyst 47
13.2.2 Changing the working directory 47
13.3 Making surface plots 48
13.4 How the interpolation of the data works 48
13.4.1 The topographic map of Pais Pesca 49
13.5 How to set a mask in a GIS analysis 53
13.5.1 Pais Pesca: Topography with mask set 54
13.5.2 Histogram of created grid files 57
13.5.3 Pais Pesca salinity grid and water depth grid 58

14 Calculation with grids using GIS 59
14.1 Map calculations 59
14.2 Reclassifying 63
14.3 Querying 64
14.3.1 Shrimp farming in the coastal areas of Pais Pesca 64
14.3.2 Protection of fish stocks and the creation of protected areas in Lake Kadim, Pais Pesca 70

15 Regression analysis 77
15.1 Linear regression 77
15.2 Regression with an Avenue script in ArcView 81
15.2.1 Regression analysis of Lake Kadim data using an avenue script 84
15.3 Regression analysis between grids with the Grid Regression tool 85
15.3.1 Grid regression of data from the fish survey at Lake Kadim 91

16 Use of ArcViews' help and other ways to expand your knowledge 93

17 Application case studies 94
17.1 Real world exercises 94
17.1.1 World fisheries statistics 94
17.1.2 Frame survey Lake Volta, Ghana 99
17.1.3 GIS analysis of catch data of artisanal fisheries in Sinaloa, Mexico 103
17.1.4 Floodplain fisheries monitoring and GIS, an example from Bangladesh 108
17.2 Surplus production models and GIS 122
17.2.1 Fisheries on the Pescan lobster (*Cherax grafiensis*) in Lake Kadim 125

17.2.2 Fisheries on the European hake (*Merluccius merluccius*) in the Mediterranean Sea 128

18 How to proceed with your own GIS work 133

18.1 Registering and digitizing an image 133

18.1.1 Registering 134

18.1.2 On screen digitizing in ArcView 138

18.1.3 Real world exercise, Rio Uneiuxi, Brazil 143

Bibliography 145

Annex A: Pais Pesca 148

Annex B: ArcView and Microsoft Excel 150

Annex C: Kriging 155

LIST OF FIGURES

Figure Number		Page
3.1	Number of riverine fishers in the districts of Pais Pesca	6
4.1	Starting ArcView	8
4.2	The entry screen of ArcView	8
4.3	Starting a New Project	9
4.4	The View window	9
4.5	Add Theme via the menu bar	9
4.6	Add Theme pop up window	9
4.7	View after Adding a Theme	10
4.8	View after Checking Checkbox	10
4.9	Saving the 'population.apr' project file	10
4.10	How to open an ArcView project	11
4.11	What we see when we open the View screen	11
4.12	Example of project file coding	11
5.1	Theme Properties of the population density Theme	12
5.2	Selecting an area for enlarging (zooming in)	12
5.3	The result of zooming in	13
5.4	View buttons	13
5.5	Getting details from the map with 'Identify'	14
5.6	How to select Auto-label	14
5.7	The Auto-label window	14
6.1	The Legend Editor for changing the properties of the graphical display of a Theme	15
6.2	Changed colours of the population density map	15
6.3	Selecting the number of classes	16
6.4	Population density map with a higher number of classes used	16
6.5	Editing the values of the classes	16
6.6	Changing the labels of a legend	16
6.7	Changed Theme	17
6.8	Save Legend	17
6.9	Load Legend	17
6.10	The menu for changing the graphical display	18
6.11	Adding a field or parameter for graphical display	18
6.12	Histogram presentation of the population density of Pais Pesca	18
6.13	The Fill Palette	19
6.14	The Color Palette	19
6.15	Moving the District town.shp Theme on top	20
6.16	The District town.shp Theme on top	20
6.17	Double histogram of the percentage of urban and rural population in the different subdistricts of Pais Pesca	20
6.18	Setting the properties of a pie chart	21
6.19	Rural and urban population displayed in combination with the total population in each district	21
8.1	The different files making a shapefile in ArcView	23
8.2	Data table and map of the subdistricts in Nerad districts, both indicating the codes used to join the data with the location of the subdistrict	24

Figure Number		Page
8.3	View contents of a shapefile table	24
8.4	The Theme table of 'Three_districts'-shapefile with subdistricts codes and names	25
8.5	Adding a table in the main menu of ArcView	25
8.6	The Add Table menu	25
8.7	The added table of 'Three_districts' with the subdistricts codes and data	26
8.8	Tiling your project window	26
8.9	Attribute table with the joined data	27
8.10	Selecting the Table Properties	29
8.11	Changing the Table Properties	29
8.12	Converting to a shapefile	30
9.1	How to get to the Field Calculator	32
9.2	The Field Calulator window	32
9.3	The Field Calculator window filled in	32
10.1	Two Attribute Tables	34
11.1	Marine fishing villages	36
11.2	Excel file with data of the survey of the coastal district	37
11.3	Excel sheet with converted GPS readings (DMS to DD)	37
11.4	Excel sheet converted to .dbf file	37
11.5	Importing the 'Marine frame survey exercise.dbf' file	38
11.6	Adding a theme with collected data from the marine frame survey	38
11.7	The Add Event Theme window	38
11.8	The villages with the number of boats	39
11.9	The distribution of gear	39
12.1	Distance units for the View projection	41
12.2	The distance between Tunis and Cape Town	42
12.3	The worldmap with circle faces	43
13.1	Grid files with pixels	45
13.2	Example of different grid layers	46
13.3	Opening the ArcView Extensions window	47
13.4	Activating Spatial analyst	47
13.5	Setting the working directory	47
13.6	Changing the working directory name	47
13.7	Two topo levels in the coastal area of Pais Pesca	48
13.8	Theoretical example of Interpolation	48
13.9	Histograms of elevation of Pais Pesca	49
13.10	Start surface interpolation	50
13.11	The Output Grid Specification window	50
13.12	Progress of surface interpolation	51
13.13	Interpolate Surface window	51
13.14	The generated grid for the topography of Pais Pesca	51
13.15	Topography Pais Pesca	52
13.16	Saving a legend style	53
13.17	The difference between a mask and a barrier during interpolation in ArcView	54
13.18	Going to Theme/Convert to Grid	54
13.19	The Convert to gridname window	54
13.20	Setting the output extent	55
13.21	Selecting the field used in the grid conversion	55
13.22	The created grid file of Pais Pesca	55
13.23	Opening the Properties of an analysis	56

Figure Number		Page
13.24	Selecting the mask for an analysis	56
13.25	Topographic map of Pais Pesca created with a mask set	57
13.26	Distribution of land with different elevation in Pais Pesca	57
13.27	Salinity levels in the coastal areas of Pais Pesca	58
13.28	Depth of the Bodor sea	58
14.1	Cross-section of the floodplain of Pais Pesca	59
14.2	The topographic level of the districts involved	60
14.3	Opening the map calculation menu	61
14.4	Calculating the water depth in the floodplain	61
14.5	Floodmap of Pais Pesca	62
14.6	Floodmap of Pais Pesca, reversed calculation	62
14.7	Starting the Data Source Manager	63
14.8	The Source Manager	63
14.9	Opening the reclassify window	63
14.10	Selecting two classes to reclassify	63
14.11	The new floodmap of Pais Pesca of October	64
14.12	Floodmap of June	64
14.13	Opening Map Query	65
14.14	Selecting the criteria for the query	66
14.15	Results of Querying shrimp farms and salinity	66
14.16	Querying with two grids and three criteria	67
14.17	Shrimp farming yield in the different salinity zones of Pais Pesca	67
14.18	Querying the mangrove grid with the shrimp farm grid	68
14.19	Shrimp farms in the mangrove forest of Pais Pesca	68
14.20	Shrimp ponds, mangrove and acid sulphate soils in Pais Pesca	69
14.21	Water depth of Lake Kadim	71
14.22	Secchi depth of Lake Kadim	71
14.23	Chlorophyll concentration in Lake Kadim	71
14.24	Carp larvae density in Lake Kadim	71
14.25	Clupeid larvae density in Lake Kadim	71
14.26	Adult carp density in Lake Kadim	71
14.27	Water temperatures in Lake Kadim	72
14.28	The query between water depth and adult carps	72
14.29	The results of the query between water depth and adult carps	72
14.30	The query between adult carps and water temperature	72
14.31	The results of the query between adult carps and water temperature	72
14.32	The query between adult carps and chlorophyll	73
14.33	The results of the query between adult carps and chlorophyll	73
14.34	The query between carp larvae and temperature	73
14.35	The results of the query between carp larvae and temperature	73
14.36	The query between carp larvae and water depth	74
14.37	The results of the query between carp larvae and water depth	74
14.38	The query between carp larvae and chlorophyll concentration	74
14.39	The result of the query between carp larvae and chlorophyll concentration	74
14.40	The query between carp larvae and Secchi disk depth	74
14.41	The result of the query between carp larvae and Secchi disk depth	74
14.42	The query between clupeid larvae and water depth	75
14.43	The results of the query between clupeid larvae and water depth	75
14.44	The query between clupeid larvae and water temperature	75
14.45	The result of the query between clupeid larvae and water temperature	75

Figure Number		Page
15.1	The relation between the number of fishers and the number of gillnets in the different villages around Lake Kadim	77
15.2	Relation between the number of fishers and their annual catch of carps	77
15.3	The Add Trendline window	80
15.4	Checking Display equation on chart and Display R-squared on chart	80
15.5	The Microsoft Excel regression between the number of fishers and their CPUE in Lake Kadim	80
15.6	The equation to calculate R-squared	81
15.7	Opening a new script	81
15.8	Loading a script text file	82
15.9	Selection of the regression script	82
15.10	Compiling a script	82
15.11	Regression error message	82
15.12	Tiling in the script view	83
15.13	Tiled script and view window	83
15.14	Activating the data theme for regression	83
15.15	Running the script	83
15.16	Selecting the independent variable	83
15.17	Selecting the dependent variable	83
15.18	Bivariate regression results	84
15.19	The scatterplot of the calculated regression	84
15.20	Two grids with values for a regression	85
15.21	The Regression Options window	86
15.22	The regression analysis progress bar	86
15.23	The analysis progress window	87
15.24	The model and ANOVA table, and the scatterplot of the analysis	87
15.25	The Model and ANOVA table	88
15.26	Scatterplot between Depth and Clupeid made with the Grid Regression extension	89
15.27	Scatterplot between Depth and Clupeids made in Microsoft Excel	89
15.28	Themes added by the Grid Regression extension to View	89
15.29	The attribute table of the data used in 'Grid Regression'	90
15.30	Clupeid density in Lake Kadim (original measurements)	90
15.31	Water depth of Lake Kadim	90
15.32	Calculated clupeid density (Model)	90
15.33	Residual plot between the original and calculated densities	90
16.1	The result of clicking the 'floodplain.shp' point Theme with the Hotlink pointer	93
17.1	Attributes of 'World.shp'	94
17.2	World fisheries production	95
17.3	Attributes of 'World.shp'	95
17.4	Sort Descending menu	95
17.5	How to get to the Theme Properties window	96
17.6	A built query	96
17.7	View of the world without China	97
17.8	World fisheries production without China	97
17.9	Start editing attributes table of 'World.shp'	97
17.10	Field definition pop-up for added field	98
17.11	Attributes table of 'World.shp' with added Field	98

Figure Number		Page
17.12	The Field calculator ready to perform the calculation	98
17.13	World fisheries per capita	99
17.14	Lake Volta with stratum 7 (in red)	100
17.15	After loading the 'N-30-05_loc.sid' Theme	101
17.16	Sinaloa state	103
17.17	Multiple data per fisheries office	104
17.18	Linking two tables	104
17.19	How to get statistics on selected records	105
17.20	The statistics window	105
17.21	Summary Table Definition	106
17.22	Cleaning up a table	106
17.23	The Attributes of office locations	107
17.24	The data of different fish species per fisheries office	107
17.25	The CPP project in Bangladesh	109
17.26	Cross-section of a typical floodplain system in Bangladesh	110
17.27	Water level and inundated area of a floodplain system at three moments during the year	110
17.28	Sampling sites of the fisheries monitoring programme in the CPP project area	112
17.29	Seasonal variation in fishing effort and CPUE in the floodplain (F3) of Bangladesh	113
17.30	The principle of querying the floodmap with the landtype map	114
17.31	Pathway of determination of monthly flooded area per habitat in the CPP project area	115
17.32	Interpolated waterlevels for January in the CPP project	116
17.33	Calculating the waterdepth	116
17.34	Calculated water depth for January in the CPP project area	117
17.35	Landtypes in the CPP project area	117
17.36	Querying the Floodmap of January and the Landtype Theme	118
17.37	Number of pixels representing flooded F3 Land	118
17.38	The Tabulate Areas window	119
17.39	Calculated area in hectares	119
17.40	Comparison between calculated flooding and Radar application	120
17.41	Comparison of Radar images for two days in September 1998	121
17.42	Schaefer curve shrimp trawling in the Bay of Bengal	123
17.43	Yield curve shrimp trawling in the Bay of Bengal	123
17.44	Schaefer curve reef fisheries Jamaica	124
17.45	Yield of reef fisheries Jamaica	124
17.46	Regression result outcome	126
17.47	Scatterplot regression	126
17.48	Exploitation status of lake Kadim, areas in green under-exploited, areas in red overexploited.	127
17.49	Summary of 'Lobster data.shp' per fishing zone	127
17.50	The European hake (*Merluccius merluccius*)	128
17.51	Regression results	129
17.52	Scatterplot regression of 'CPUE_Hake' vs 'Effort_Hake'	129
17.53	Depths at the Tyrrenean coast	129
17.54	The worksheet of hake data	130
17.55	The attractor function	131
17.56	Schaefer curve hake fisheries Thyrrenean coast	131
17.57	The query for underexploited areas in the Thyrrenaen Sea	132
17.58	Over- and under-exploited areas in the Thyrrenean Sea according to the Corsi model	132

Figure Number		Page
18.1	Pais Pesca floodplain biodiversity study	134
18.2	Georeference Tiff Image extension	135
18.3	The new Georeference Tiff image extension button	135
18.4	Georeference Points window	136
18.5	Theme properties of the registered image	136
18.6	Two Themes, to check the registration process	136
18.7	The New Theme dialogue box	138
18.8	Table Of Content indicating which Theme can be edited	139
18.9	The Drawing Tool button	139
18.10	Following the outline of a waterbody	139
18.11	The completed polygon. See the eight squares around it, indicating it is active	139
18.12	The polygon, after changing the Legend to show only the outline in red	140
18.13	The polygon, after pressing the Vertex Edit tool button	140
18.14	The Attributes table of the New Theme, with the added field 'WaterBodyNumber'	141
18.15	The Attributes table with a record selected	141
18.16	Image of Rio Uneiux with georeferenced points	143
18.17	The Attributes table with a record selected	144
A.1	The Pais Pesca flag	148
A.2	Pais Pesca and her neighbours	148
A.3	Elevation map of Pais Pesca	149
A.4	Main land-uses in Pais Pesca	149
B.1	The different files making a shapefile in ArcView	150
B.2	The Open File dropdown list	151
B.3	Formatting your cells in Excel	151
B.4	Saving a spreadsheet as a .dbf file in Excel	152
B.5	The SQL Connect window	153
B.6	Selecting the correct Excel file for the SQL connection	154
B.7	Making a table from Excel data using SQL	154
C.1	Making the Spatial Tools extension active in ArcView	155
C.2	A semi variogramme	156
C.3	Selecting the Z-value for Kriging	158
C.4	Use barrier?	158
C.5	Selecting the type of Kriging	158
C.6	Selecting the type of model to use for Kriging	158
C.7	The lag scheme	159
C.8	The Lag Interval window	159
C.9	Saving the result of the kriging as a dBase file	159
C.10	Naming the variogram	159
C.11	Coding of the variogram	160
C.12	Layout of the generated variogram	160
C.13	Start interpolation?	160
C.14	Chosing the method of interpolation	160
C.15	Chosing the type of radius	161
C.16	Entering the radius parameters	161
C.17	Creating an output grid?	161
C.18	Kriged waterdepth	161
C.19	Variance of water depth after Kriging	161
C.20	Semi variogram made with a 5 metres lag interval	162
C.21	Semi variogrammade with a 100 metres lag interval	162

LIST OF TABLES

Table Number		Page
3.1	Number of riverine fishers in the districts of Pais Pesca	6
8.1	Sample data of theme table for 'Pais_pesca_country.shp'	24
8.2	Fisheries data Pais Pesca of 2001	28
9.1	Prawn prices per district (2001)	31
11.1	Location of villages in decimal degrees	36
11.2	Decimal degree conversion to DMS exercise	36
12.1	Types of projections	40
13.1	Areas of different elevations	58
14.1	Example of calculation of water depth in the floodplain of Pais Pesca	59
14.2	Salinity and number of shrimp farms	67
14.3	Area of shrimp ponds according to average yields in the mangrove belt of Pais Pesca	69
15.1	Data for the calculation of the regression between the number of fishers and the number of gillnets at Lake Kadim	78
15.2	Relation between the number of fishers and the CPUE of carps in Lake Kadim	79
15.3	Results of regression analysis of the raw data of Lake Kadim	84
15.4	Results of the Grid regression between the different data grids of Lake Kadim	91
17.1	Estimated catch of Lake Volta 1969–1977	100
17.2	Spanish, Scientific and English fish species names	107
17.3	Land classification according to the Master Planning Organization, Bangladesh	111
17.4	Fisheries data (1997) from F3 sampling sites	113
17.5	Fisheries data (1997) from F2 sampling sites	113
17.6	Frame for the estimation of the monthly floodplain catch in the CPP project	114
17.7	Estimated monthly flooded area for F3 and F2 landtypes in the CPP project area	119
17.8	Comparison of fisheries analysis using radar or GIS data	120
17.9	Shrimp trawling data from the Bay of Bengal	122
17.10	Jamaican reef fisheries data	124
18.1	Georeferenced points of figure 18.1	135
18.2	Coordinates of villages in figure 18.1	137

ACKNOWLEDGEMENTS

We would like to thank the Environmental Systems Research Institute (ESRI, Inc.), for their support to this manual. We are especially grateful to Jack Dangermond (president and founder of ESRI) and Jim Henderson (ESRI, international technical marketing and training) for their donation of copies of free software to support this manual. This donation will enable institutes/organizations in developing countries to perform spatial analyses of their data using GIS. Institutes or organizations meeting the necessary criteria[1] are eligible for this software donation. Please contact authors of this manual for details.

Special thanks are due to Geoff Meaden (Fisheries GIS Unit, Canterbury Christ Church University College, UK), who gave valuable advice and very kindly reviewed this manual.

Many thanks go to Tony Booth of the University of Alaska Fairbanks for his reviewing and comments on the chapter on Kriging. In addition, many thanks go to Jim Kapetsky who prepared the overview of past activities at FIRI.

Parts of the manual by de Graaf *et al.* (2000) were used for this manual, and the kind permission of Nefisco foundation, Amsterdam and the Center for Environment and GIS for Water Sector Planning (CEGIS), Dhaka is greatly acknowledged. The manual by de Graaf *et al.* (2000) was written with funding from the Government of the Netherlands in cooperation with CEGIS in Dhaka for use in Bangladesh.

The manual was tested in Namibia and Uganda. The test course in Namibia was hosted by the National Marine Information and Research Centre, Swakopmund, with support from the Norwegian Agency for Development Cooperation and the one in Uganda was hosted by the Ugandan Fisheries Resources Research Institute and the EU-funded Lake Victoria Fisheries Resources Project. Comments for improvements on the manual made by the students during the courses in Namibia and Uganda are greatly appreciated.

Claudia Riva made a final quality check on the data and exercises presented in this manual.

For the real world exercises data and methods were made available by Paul Eastwood, Geoff Meaden, Arturo Ruiz and Fabio Corsi.

Design and layout were by Nadia Pellicciotta.

---

[1]Criteria for software donation:
The institute/organization should be:

- located in a developing country, to be determined by whether or not the country is on the world bank list of low income and lower middle income countries (see the world bank list: http://www.worldbank.org/data/countryclass/classgroups.htm#Low_income);
- involved in research or education in inland fisheries biology/management/planning ;
- a non-profit organization;
- recognized nationally or regionally by the government(s) involved;
- in need of support in respect with software;
- endorsed by the FAO's Regional Aquaculture/Fisheries Officer (Bangkok, Thailand; Accra, Ghana; Santiago de Chile, Chile).

ABBREVIATIONS[2]

ALCOM	Aquatic Resource Management for Local Communities Development Programme
ANOVA	Analysis of Variance
AWRD	African Water Resource Database
BLUE	Best Linear Unbiased Estimator
CEGIS	Center of Environment and GIS for water sector planning, Dhaka, Bangladesh
CPP	Compartmentalization Pilot Project, Tangail, Bangladesh
CPUA	Catch per unit of area
CPUE	Catch per unit of effort
COPEMED	Cooperation in the Mediterranean
DD	Decimal degrees
DEM	Digital Elevation Model
DMS	Degrees Minutes Seconds
DoF	Department of Fisheries
EU	European Union
ESRI	Environmental Systems Research Institute, Inc.
FAO	Food and Agriculture Organization of the United Nations
f	Fishing effort
FIDI	Fishery Information, Data and Statistics Unit of the FAO Fisheries Department
FIRI	Inland Water Resources and Aquaculture Service of the FAO Fisheries Department
F_{MSY}	Fishing effort at maximum sustainable yield
GDP	Gross Domestic Product
GPS	Global Positioning System
GIS	Geographic Information Systems
ha	Hectare
IDAF	Integrated Development of Artisanal Fisheries
IDW	Inverse Distance Weighted
MBV	Monodon baculo virus
MPO	Master Plan Organization
MSY	Maximum Sustainable Yield
SQL	Structured Query Language
UNEP	United Nations Environment Programme
UNITAR	United Nations Institute for Training and Research

[2] For definitions of GIS terms, please see:

1. On-line dictionary of GIS terms by the Association for Geographic Information and the University of Edinburgh Department of Geography. http://www.geo.ed.ac.uk/agidict/welcome.html
2. ESRI GIS Glossary (available in two formats):

a) On-line: http://www.esri.com/library/glossary/a_d.html

b) Publication (ESRI, 2001), available at http://www.evansvillegis.com/PDF/GIS_Dictionary.pdf

1 Introduction

Fisheries management and planning has many spatial components (e.g. movements and migrations of resources, definition of fishing grounds, transportation networks, markets), and many serious issues like habitat loss and environmental degradation have spatial dimensions, so fisheries biologists, aquatic resource managers and decision makers in developing countries have to address issues of great complexity. In this regard, GIS is a technology that can help to clarify the issues and lead to solutions by treating many spatial components simultaneously. However, many people are still unaware or afraid of the technology and its potential for fisheries management.

This manual is written to overcome this knowledge-gap. It is not a GIS course, but more a "do-it-yourself"-course giving a short introduction to GIS software and its applications. Different examples and exercises will introduce you to several possibilities of application of GIS in fisheries (inland or marine) management. You are encouraged to apply this knowledge and your creativity to explore additional possibilities within the software. The overall objective of this manual is to encourage the use of GIS to foster the sustainable use of natural resources. Users of this manual will be able to apply learned principles and GIS to their own professional situation and will become aware of the vast possibilities that GIS can provide, so that communication with GIS expert counterparts will be easier.

During the last decade, the application of GIS in fisheries has increased as presented (as recent developments of spatial analysis) at the first and second International Symposium on the use of GIS in fisheries and aquatic sciences (Nishida, Kailola and Holingworth, 2001; Nishida, Kailola and Holingworth, in press); the FAO COPEMED Project [http://www.faocopemed.org/en/index.htm], and two excellent handbooks (FAO, 1991a and Valavanis, 2002). However, most of the publications are scientific and deal with marine fisheries in the western hemisphere.

Practical manuals, explaining the basic of GIS and its use in fisheries, aquaculture and management for developing countries, are difficult to find. Except for the manual developed by de Graaf *et al.* (2000) for Bangladesh, the only other manual similar to the present one was developed with software called 'Idrisi' and it only includes one exercise on aquaculture suitability. The workbook was developed and is distributed by Clark Labs (http://www.clarklabs.org/home.asp) through a memorandum of understanding with the United Nations Institute for Training and Research (UNITAR). The workbook explores the use of GIS analytical techniques in the defined field of study, complete with extensive bibliography and includes a set of exercises that allows the user to apply these techniques to geographically diverse case study problems using real digital data sets and GIS software. Volume 3 of the workbook series explores the role that GIS may play in coastal zone research and management and includes an exercise on aquaculture suitability analysis, Gulf of Nicoya, Costa Rica that is based on the study by FAO (1987a).

This manual is useful for a broad range of fishery applications. However, this manual by no means covers all possibilities of GIS, it merely touches upon some of the most important features for fisheries management. Interested readers are highly encouraged to become aware of past and current activities at FIRI to enrich their training.

1.1 GIS AND REMOTE SENSING ACTIVITIES AT THE INLAND WATER RESOURCES AND AQUACULTURE SERVICE (FIRI)

1.1.1 Past activities at FIRI from 1985 to 1999

The activities of FIRI in respect to GIS, most relevant to this manual, can be divided in two main categories, namely training courses and projects. The aim of the training courses was to instil an appreciation of benefits and constraints of GIS and remote sensing. Both aquaculture and inland fisheries were covered. Courses were held in Rome (Travaglia and Appelkamp, 1985), Asia (FAO, 1989b), Anglophone Africa (FAO, 1991b), Francophone Africa (FAO, 1992), and in Latin America. A manual for self-training on GIS and remote sensing applications was produced (FAO, 1991a) and it is still being widely disseminated to date as much of the main text remains relevant (see http://www.fao.org/DOCREP/003/T0446E/T0446E00.HTM).

The objective of the projects was to demonstrate the capabilities of GIS and remote sensing to address aquaculture and inland fisheries issues, mainly for strategic planning. Projects included assessments of coastal aquaculture potential in Costa Rica in cooperation with UNEP (FAO, 1987a), Malaysia (FAO, 1989a), and Sri Lanka (FAO, 1999b), and remote sensing was used to inventory shrimp farms, also in Sri Lanka (FAO, 1999a). Inland fish farming potential was assessed in Ghana in (FAO, 1991c and FAO, 1990).

A continent-level assessment of inland fish farming potential was carried out for Africa (Kapetsky, 1994b) along with an appraisal of the potential of aquaculture to contribute to food security (Kapetsky, 1995), and Africa was subsequently reassessed on the basis of improved data (FAO, 1998b). Latin America constituted another continental assessment (FAO, 1997a), and the Caribbean Island States (FAO, 1998a) and Southern Africa (Kapetsky, 1994a) were assessed as regions.

Not all of the outputs dealt with aquaculture. The use of remote sensing to inventory small water bodies for community fishery development was assessed in Zimbabwe (FAO, 1987b). At global level an assessment was carried out to estimate the potential for inland fishery enhancements (FAO, 1998c), and GIS applications in inland fisheries were reviewed worldwide (Kapetsky, 2001).

1.1.2 Current activities

Two current activities at FIRI are most relevant to this manual and are highly recommended to the readers to complement the contents found in the present manual: (1) the Global Gateway to GIS, Remote Sensing and Mapping for Aquaculture and Inland Fisheries and (2) the African Water Resource Database.

The Global Gateway to GIS, Remote Sensing and Mapping for Aquaculture and Inland Fisheries

There are many opportunities to use GIS and remote sensing to improve the sustainability of aquaculture and inland fisheries and fundamental issues in aquaculture and inland fisheries can be resolved with the help of GIS and remote sensing. However, overall, our research has concluded that the aquaculture and inland fisheries GIS user base is low. Therefore, the objectives of this Gateway are to: (1) improve the sustainability of aquaculture and inland fisheries by promoting the use of GIS, remote sensing and mapping; (2) facilitate the use of GIS, remote sensing, and mapping through easy access to comprehensive information on applications and training opportunities; and (3) provide a "one stop" site from which to obtain the depth and breadth of the global experience on GIS, remote sensing and mapping in aquaculture and inland fisheries.

The Gateway is being designed for a very broad range of users. The beneficiaries will mainly consist of people working with global and regional analysis on aquaculture and inland fisheries management and planning, including researchers and project

managers in national and international organizations and scientific institutes. Other beneficiaries are the commercial sector and planners and managers in fields apart from aquaculture and inland fisheries, specifically those involved with coastal area management and river and lake basin management.

The Gateway is a work in progress at FIRI and will be located in FIGIS (http://www.fao.org/figis/index.jsp) in early 2004.

African Water Resource Database (AWRD)

The African Water Resource Database (AWRD) is a Geographic Information System (GIS) analytical framework supporting natural resource planning with a specific focus on inland fisheries and integrated water resource management. The present AWRD is an expansion and enhancement of the work by ALCOM's Water Resource Database (http://www.fao.org/fi/alcom/wrd.htm) for subequatorial Africa which has been extended to cover the entire African continent. Development of the AWRD is a work in progress being carried out under the guidance of FIRI.

The core datasets which populate the AWRD include: various depictions of surface water bodies, multiple watershed models; aquatic species; rivers; administrative boundaries; population density; soils; satellite imagery; and many other physiographic and climatological data types. To display and analyse the data, the AWRD contains an assortment of new custom-designed applications and tools. These tools are designed to facilitate integrated water resource management and planning, as a means of promoting the responsible management of living aquatic resources and increasing food security.

The beneficiaries of the AWRD will mainly consist of people working with global and regional analysis on water and inland aquatic resource management and planning, including researchers and project managers in national and international institutions.

The tools developed for the AWRD are for use with ESRI's ArcView 3.x and Spatial Analyst software, so we recommend the readers to explore the AWRD once they have become acquainted with GIS-basics using the GIS manual in front of you.

The first version of the AWRD will be made available in early 2004 as an FAO technical publication and a set of CD-ROM data disks.

2 Training with the manual

The manual has two distinct parts or user skill levels. The first part presents the basics of GIS by providing a quick overview of the most important functions of ArcView and the Spatial Analyst extension. This part uses data from the fictitious country Pais Pesca[3]. This country was chosen so that the authors were able to develop exercises without giving information which is incorrect. If you want to know more about the specifics of the country, have a look at Annex A. If you have basic computer skills (2–5 years of PC experience, worked with Microsoft Excel) you should be able to complete at least:

a. GIS basics, pages 1–44,
b. application case studies, pages 94–132, and
c. how to proceed with your own GIS work, pages 133–144.

The second part is based on raster data and earlier publications, illustrating practical applications of GIS from going from global fisheries statistics, to floodplain fisheries monitoring, to hake fisheries in the Italian Tyrrhenian Sea.

2.1 SET UP OF THE TRAINING AND THE MANUAL

As mentioned before, this manual is a 'do-it-yourself' manual. The complete package consists of this manual and two CDs with exercises. For the use of the manual you need to have ArcView installed, and later on the Spatial Analyst extension. The system requirements for ArcView 3.3 are:

- Industry-standard personal computer with at least a Pentium or higher Intel-based microprocessor and a hard disk.
- Memory: 24 MB RAM (32 MB recommended).
- Operating System: Windows 98/98SE, Windows Me, Windows NT 4.0, Windows 2000, and Windows XP (Home Edition and Professional).

ArcView Spatial Analyst 2 requires ArcView 3.2 or higher and is supported on: Microsoft Windows, Windows XP (Home Edition and Professional), Windows 2000, Windows NT 4.0, and Windows 95/98.

ArcView Spatial Analyst 1.x is supported on Microsoft Windows, Windows NT 4.0, and Windows 95/98.

To install ArcView and the Spatial Analyst extension: put the ArcView installation CD in your PC and follow the instructions on your screen. After the installation of ArcView is complete you might be asked if you want to install Seagate Crystall reporting. This will take a lot of space on your hard disk, and for the exercises in the manual you do not need it, so press **No**. After you have installed ArcView, you should install the Spatial Analyst extension: put the installation CD of the Spatial Analyst extension in you PC and follow the instructions on your screen.

After successful installation of both ArcView and the Spatial Analyst extension, you can start with the course. Depending on the space available on your hard disk you could copy both exercise CDs onto your hard drive in one folder (for instance: /FAO_GIS/). If you do this, you have to make sure that the whole path is without spaces and long names, as ArcView has problems with these types of paths (do not copy the data into your 'My Documents' folder, as this folder's path contains a lot of

[3] With kind permission of Resource Analysis, developers of Fishman (http://www.netcoast.nl/coastlearn/website/planning/fishman.htm).

spaces which ArcView handles badly [see also the naming convention note on page 52]).

When your hard disk space is limited, leave all data on the CDs, and work from the CDs. This option will decrease the speed of operation of the PC. You may find that some exercises do not work in this way. If this is the case, copy the data you need onto your hard disk, and try again.

Pay special attention to the fact that when you copy files from a CD onto your hard disk, these files will have the properties as Archive and Read only. To be able to work with the files, you will need to change the properties of the files you use: open the Windows Explorer, right-click on the file(s) you copied and are going use, click properties, and look in the General tab under Attributes (at the bottom). All tick boxes need to be empty. If one of the boxes is ticked, untick it, so that the files can be edited.

3 What is GIS?

People have made maps for thousands of years to present and analyse information. **Geographic Information Systems** or **GIS** is a computer system for capturing, storing, checking, integrating, manipulating, analysing and displaying data related to positions on the Earth's surface.

An example:

The Pais Pescan department of fisheries collected data on the number of fishers in different districts of Pais Pesca and published them in the form of tables such as those presented in Table 3.1 below.

Questions GIS can answer:

1. Location:	What is at...?
2. Quantification:	How big, How long, How many in...?
3. Routing:	What is the best way to...?
4. Condition:	Where is it...?
5. Trends:	What has changed since...?
6. Patterns:	What spatial patterns exist...?
7. Modelling:	What if...?

(COPEMED, 2001 a; b)

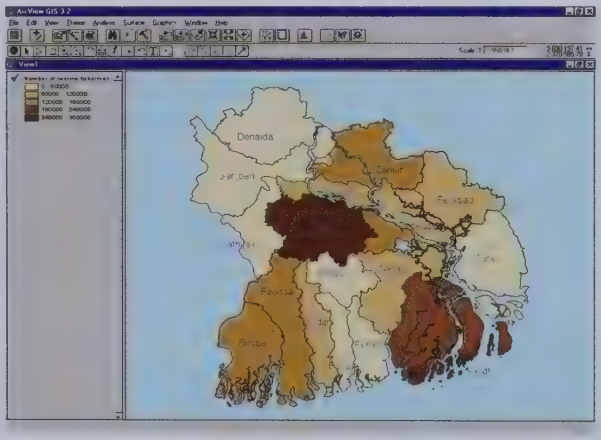
TABLE 3.1

Number of riverine fishers in the districts of Pais Pesca

District name	Number of riverine fishers
Bandarbadan	142 174
Bargun	49 867
Boldan	101 860
Cankir	129 457
Dadon	90 561
Denaida	40
Faodoa	147 191
Felixsad	117 989
Ganjpani	42 455
Goodt	219 005
Grumara	297 070
Kathijalo	53 302
Muladi	51 432
Nerad	107 853
Pepedas	80 016
Puradi	57 255
Siraba	121 353
Tara	45 775

FIGURE 3.1

Number of riverine fishers in the districts of Pais Pesca



The same information can be presented in the form of a map as presented in Figure 3.1. In this case, because there is very little information, both the table and the map are easy to use but the situation changes if we want to present the data of all sub-districts of Pais Pesca. There would be so much information, that tables of several pages would be needed, and it is clear that presenting the data in the form of a map then is more comprehensive.

In the example, the number of fishers were presented in the form of a map, but of course any information obtained from a district, sub-districts, etc. can be visualized in such a way, i.e. the number of fishing boats per district, literacy rate per district, the number of fish markets per district, the number of schools per district.

GIS is nowadays the principal tool for presenting and analysing georeferenced data,

that are data collected from a known location. GIS has the following advantages (FAO, 1996):

GIS allows for the display of spatially related data in a way that is easily comprehensible for most people;

Once maps have been made in digital format, it is a simple task to update them, to change them, or to merge them with other maps in order to create new maps;

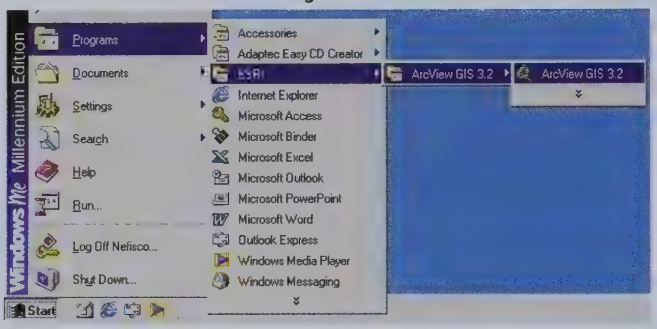
GIS allows for the easy and immediate integration of other large data sets, i.e. enabling technologies of, for instance, GIS and remote sensing, or GIS and radar, to be readily combined;

GIS allows a regular flow of spatially related information in a standardized format. This might be for a given time series in which all maps are produced together, or it might mean that periodically a new version of the same map could be produced.

4 Starting ArcView

Once you have installed ArcView 3.x on your computer you can start it by double clicking on **ArcView GIS 3.x** located in the taskbar **Programs/ESRI/ArcView GIS 3.x**.

FIGURE 4.1
Starting ArcView



Or by clicking on the **Quick start**-icon of ArcView visible on the desktop screen after you start the computer.

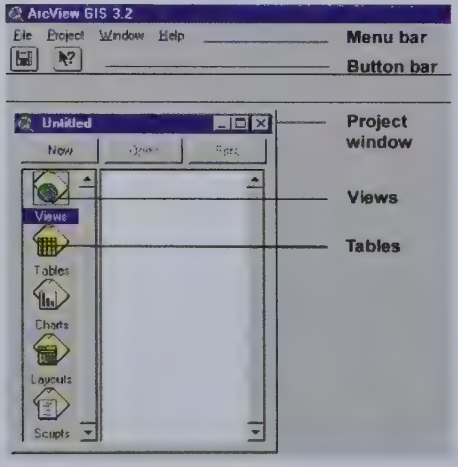
When you start ArcView you will see the entry screen of ArcView (Figure 4.2), which contains a menu bar (**File, Project, Window, Help**), a button bar for opening and saving of projects, changing options in ArcView, and a vertical project window toolbar which starts the different applications of ArcView. For your work, the **View**-icon and the **Table**-icon are of importance. You can forget all the others for the time being.

The **Project window** contains all data belonging to a project (Views, Tables, Charts, etc.)

In **View** all the GIS spatial procedures, calculations, and analyses are carried out and data are displayed.

In **Table**, all data, which are joined with a location on a map, are stored.

FIGURE 4.2
The entry screen of ArcView



4.1 STARTING ARCVIEW AND ADDING A THEME

Have a better look and familiarize yourself with some features of ArcView. Start ArcView, and open a new project (**File/New Project** via the menu bar, see Figure 4.3).

FIGURE 4.3
Starting a New Project

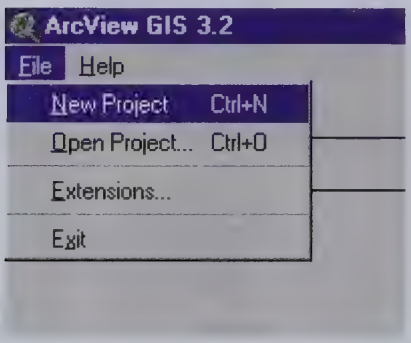
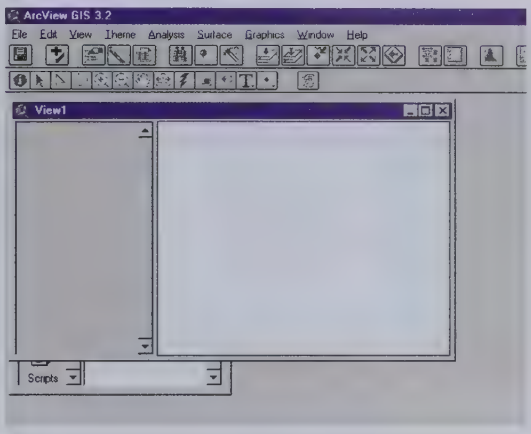


FIGURE 4.4
The View window



You will see the ArcView entry screen (Figure 4.2), press the **New** button of the Project window, while the **Views** icon is active (like in Figure 4.2). The **View** window will pop up (Figure 4.4).

Press the **Add Theme**-button on the left side of the Button bar , or go to **View/Add Theme...** via the menu bar (Figure 4.5).

FIGURE 4.5
Add Theme via the menu bar

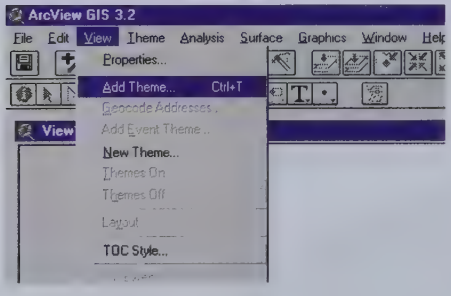
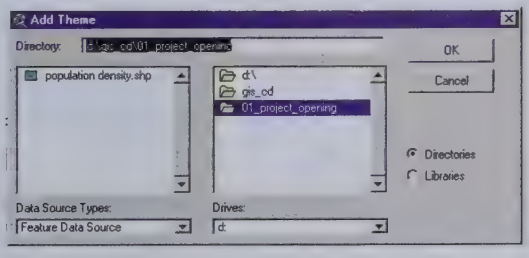


FIGURE 4.6
Add Theme pop up window



The **Add Theme** pop-up window will appear (Figure 4.6). Here you need to tell the program which Theme you want to use. Go to the '01_project_opening' folder on the CD that comes with this manual. Select 'Population density.shp' and press **OK**.

Note:

Whenever apostrophes (') are used in this manual you need to copy the term or name that is mentioned within these apostrophes, ignoring the apostrophes themselves.

The Theme will be loaded resulting in the View as in Figure 4.7. If you put your mouse pointer on the checkbox, and click, you will see a chart displaying the population density of Pais Pesca (Figure 4.8). You see that areas with a high population density have a darker colour of red, while the areas with a low population density have a very light colour.

FIGURE 4.7
View after Adding a Theme

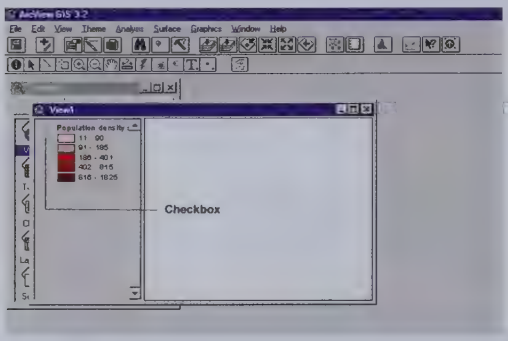
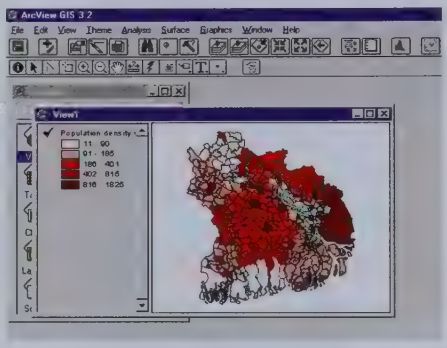


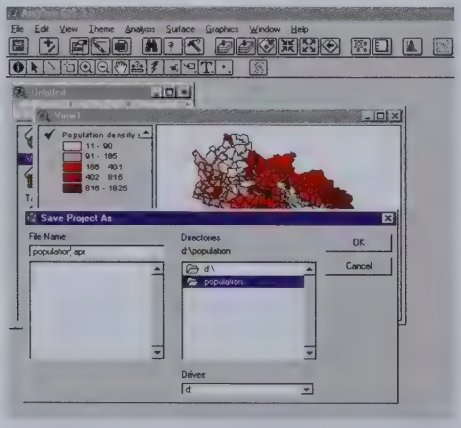
FIGURE 4.8
View after Checking Checkbox



Now you need to save this file as a Project (what a project exactly is, and what it does, you will learn in the following paragraph). Save this project as 'population.apr' in a separate folder. You can save this project file in any folder you want, and it is a good idea to make a folder per exercise, so first generate (with Windows Explorer for instance) the folder: 'Population' on a drive that has a lot of space.

1. Save the project file in the folder you just created: Go to **File/Save Project** via the menu bar, and you will see the **Save Project As** window pop-up (Figure 4.9). Put the filename ('Population.apr') in the File Name: box, and click **OK**.
   Now you have saved the project.
2. Close everything and exit ArcView via the menu bar: **File/Exit**.

FIGURE 4.9
Saving the 'population.apr' project file



4.2 OPENING AN ARCVIEW PROJECT

Start ArcView and open the project you made in the previous exercise, by selecting the **File/Open Project** via the menu bar. In the **Open Project** window select the drive where you stored the folder 'Population', in the 'Drives:' box. Navigate in the 'Directories box' to the folder you made, by double-clicking the correct folders. Finally open the project by double clicking 'population.apr' in the left window (Figure 4.10) or by selecting 'population.apr' and then click **OK.**

When the project opens you see exactly the same View as it was when you saved the Project 'population.apr'.

In the **View**, we see the map in the 'Map Display', the 'Theme Title', the 'Theme Legend' and the 'View Checkbox' in the 'Table of Contents' (Figure 4.11).

FIGURE 4.10
How to open an ArcView project

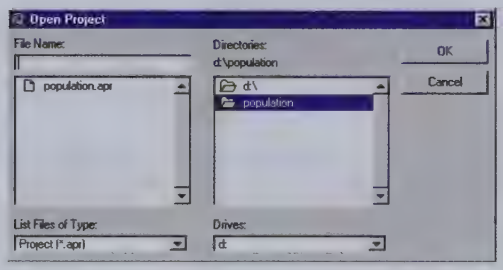
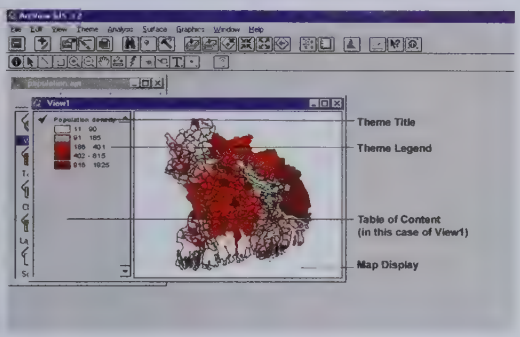


FIGURE 4.11
What we see when we open the View screen



4.3 WHAT IS AN ARCVIEW PROJECT

To understand better how ArcView works it is essential that we explain the structure of a **Project** and what it contains. In principle, a **Project** is a file that contains exactly what you have done during an earlier ArcView session. Once you open the **Project**, ArcView repeats the procedures exactly as you have carried them out before.

An ArcView project does not contain data. It contains the information on how ArcView needs to find the data in your computer, and how to put them together again, to have the same result as when you saved the project last.

FIGURE 4.12
Example of project file coding

```
Name:       "population.apr"

    Name:       "Population density"

    Name:       "subdist.shp"
    SubName:    "Polygon"
    Path:       "c:/fao-fish-gis/pais pesca/shape files/subdist.shp"

    Name:       "subdist.dbf"
    Path:       "c:/fao-fish-gis/pais pesca/shape files/subdist.dbf"
```

In Figure 4.12, an example is presented of a small part of a project called 'population.apr' written by ArcView. When this project is opened, it will search for a polygon file containing the borders of the sub-districts called '**subdist.shp**' which is located in the subdirectory 'C:\FAO_FISH_GIS\Pais shape\Shapefiles\'. It will also search for a Dbase-file containing the data on population density for each sub-district called 'subdist.dbf' located in the same subdirectory.

The consequence of this is that when you change the location of your basic input data for a project on your computer, this project cannot find this data, and you will get all kinds of messages/requests concerning the location of files after you open a **Project**. In those cases, i.e. when you put the 'subdist.shp' of our example somewhere else, you will have a problem if you do not know where you have placed it.

During the training, you will be asked to open or add a number of different files and therefore some clear definitions:

A **Theme** file is a file that contains geographical data in the form of Maps. It can be either location of places with no further data attached, or files with locations and data attached. Themes are Shapefiles, Grids, Images or Vector files.

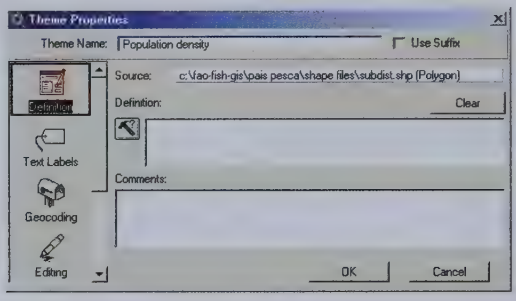
A **Table** file is a data Table often with one column where a reference is given to a certain location in one of the Theme files.

5 Some Tools in View

Open the project you needed to open in paragraph 4.2, Opening an ArcView Project. A Theme can be turned on or off by checking the checkbox. By clicking on a Theme in the Table of Contents, this Theme can be made active and will appear raised in the Table of Contents.

Once the Theme is active and we click on the **Theme Properties**-button, the properties of this Theme are displayed (Figure 5.1).

FIGURE 5.1
Theme Properties of the population density Theme



From the **Theme Properties** we see the name of the Theme and the original data source, which is a polygon shapefile found in the folder you designated, called 'population density.shp'.

In this tool we can manipulate the original data displayed. In the first box, the name is given of how this theme is displayed in the View. Here this name can be changed without changing the name that is saved in the computer. In our case the Theme name visible in the View is 'Population density.shp'.

Change the Theme name in this window to 'Population density' (without the '.shp'), click **OK** and look at the displayed name in the View.

With the **Zoom in and out**-button in the toolbar we can make areas of interest larger by placing the cursor near the place of interest and dragging it till the area of interest is selected (Figure 5.2).

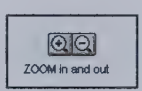
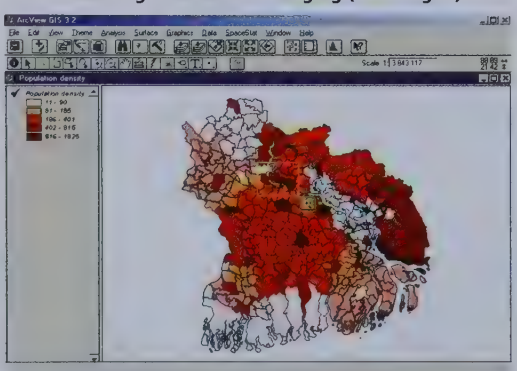
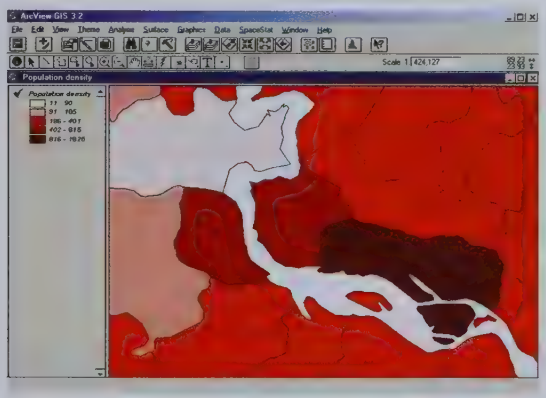


FIGURE 5.2
Selecting an area for enlarging (zooming in)



After releasing the mouse button, the view will be redrawn in the magnified scale (Figure 5.3). Before you do this, you might want to maximize the window, so that your whole screen displays the ArcView window.

FIGURE 5.3
The result of zooming in



Once you have zoomed in and you want to go to another location, you can move the map with the **Pan** icon. Try this out by zooming on the central part of Pais Pesca and then pan from north to south and from west to east.

After zooming and panning, you probably will have lost track of where you are, and how to get back. You can go via the menu bar to **View/Full Extent**, which will show you the complete Theme again. Another option is to use one of the six View buttons in the button toolbar (Figure 5.4). Try these buttons, and see what they do.

FIGURE 5.4
View buttons

Identify is a tool to get more information on the separate items displayed in the map. Once the tool is activated by clicking on the button with your mouse pointer, your pointer symbol on the screen changes into a cross with an 'i' next to it. Try this, click on the identify button, and move the pointer over the View, you will see that it has changed. If you click now on an item/location in the map, detailed information of the table attached to the map for this location is automatically made visible (Figure 5.5).

By clicking with **Identify** on a sub-district, the data of this sub-district (attached to this **Theme**) automatically pop up. By doing this we can see for instance the name: **HEROS**, the number of the sub-district: **502**, the name of the district: **Dadon**, etc.

We can use this tool to find a sub-district if we do not know exactly where it is, but this means that you have to click on a large number before you have found it. Try to find the sub-district named 'Wolffi' this way (northeast of Heros).

This can be done much more easily with **Auto-label**. You can add the name of the sub-district by selecting **Auto-label** in the **Theme** menu (Figure 5.6).

FIGURE 5.5
Getting details from the map with 'Identify'

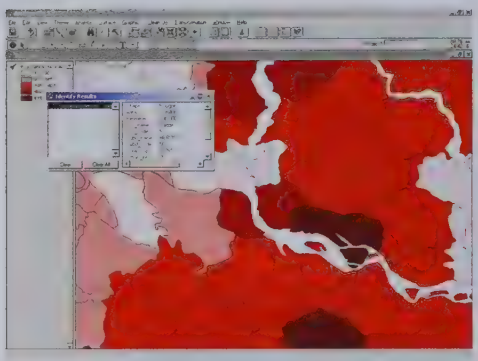


FIGURE 5.6
How to select Auto-label

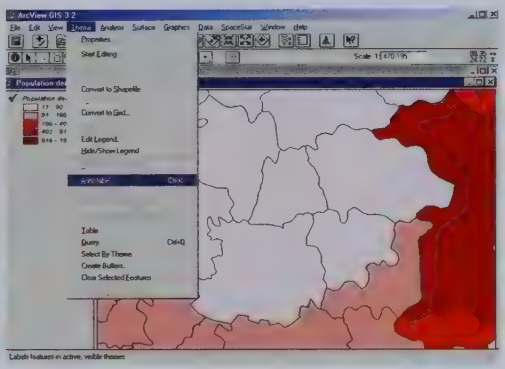
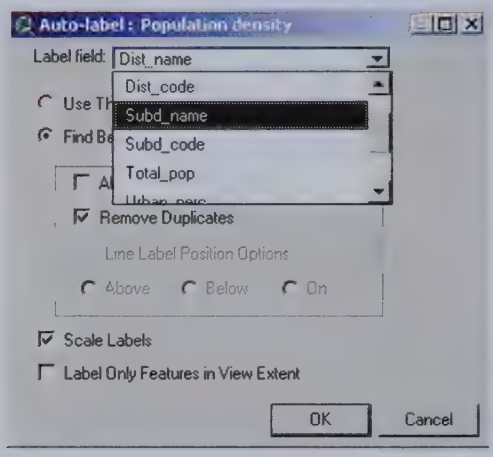


FIGURE 5.7
The Auto-label window



The **Auto-label** window (Figure 5.7) will popup, select 'Subd_name' in the Label field box and click **OK**.

Note: the first time you do it, you often see a large number of names overlapping and you hardly can distinguish anything. Zoom in further to provide enough space for each individual sub-district name.

Try to do this: Zoom in on the coast, Auto-Label the sub-district names and try to find the sub-district named 'Gramma'. Using the 'Pan' tool now will make it easier.

The labels can be removed by clicking in the **Theme menu** on **Remove Labels.** Try this; remove the labels, and **Auto-label** again with 'Dist_name'.

Note: The district names are best displayed if you zoom out before **Auto labelling.**

Note: In the **Auto-label** window you see two small Check-boxes: **Allow Overlapping Labels** and **Remove Duplicates.** The default setting of ArcView is **Remove Duplicates**, i.e. the same name is never displayed twice. Try this, remove the labels, and **Auto-label** again with 'Dist_name' with **Allow Overlapping Labels** ticked and **Remove Duplicates** not ticked.

6 Graphical displays in the Map View

6.1 CHANGING COLOURS OF A LEGEND

Start ArcView, Open a New Project, and Open a New View. Add the Theme 'population density.shp' from the folder '02_Graphical display' on the CD. Check the Legend Checkbox. The map is a representation of data collected by the Bureau of Statistics of Pais Pesca presented on in gradual changing colours, whereby increasing red tones indicate a higher population density. (It is the same Theme as you worked with in the previous paragraph). The number of classes of colour tones as well as the colour itself can be changed easily by double clicking on the Theme legend, or by going via the menu bar to: **Theme/Edit Legend**, after which the **Legend Editor** window pops up (Figure 6.1). Click on the right downward arrow of the **Color Ramps** box and select 'Yellow monochromatic'. Click on **Apply**, close the **Legend Editor** window. You will notice that all colours are changed into gradually changing Yellow (Figure 6.2). Try out changing the colours successively into: Yellow monochromatic; Blue monochromatic; and Magenta monochromatic.

FIGURE 6.1
The Legend Editor for changing the properties of the graphical display of a Theme

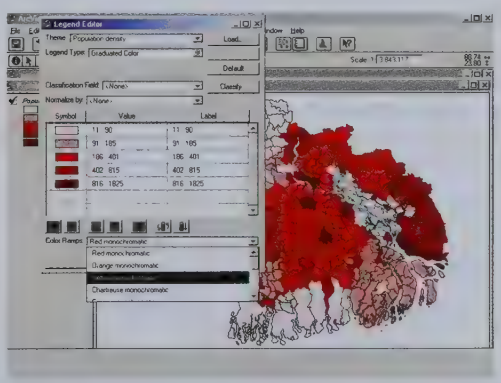
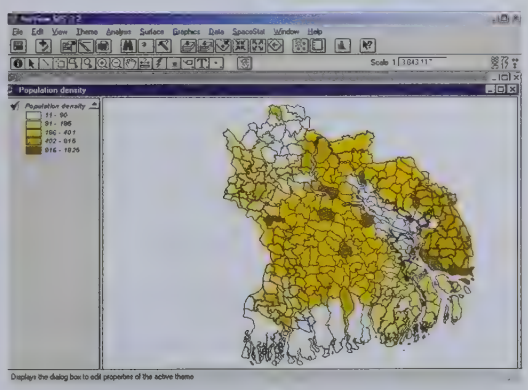


FIGURE 6.2
Changed colours of the population density map



6.2 CHANGING THE NUMBER OF CLASSES IN A LEGEND

In the previous example, differences in the population for the different sub-districts were visualized by using only five classes, and it could be that more details become visible if a larger number of classes were used. Changing the number of classes over which the data are divided can be changed in a similar way as changing the colours. Double click on the Theme legend, or by going via the menu: **Theme/Edit Legend**, after which the **Legend Editor** window pops up. Click on **Classify** after which the **Classification** window pops up. Select 15 classes after opening the **Number of classes** screen with the small arrow on the right (Figure 6.3). Click **OK**, **Apply,** and close the **Legend Editor** window. The new classification will be displayed (Figure 6.4).

FIGURE 6.3
Selecting the number of classes

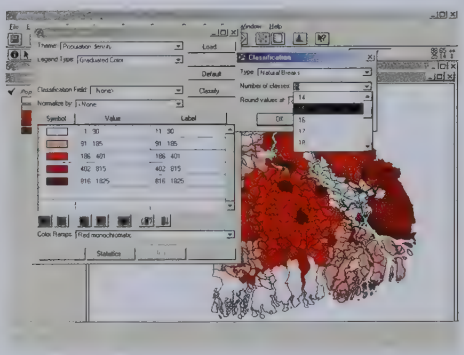
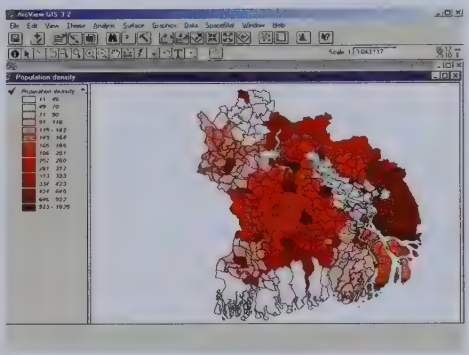


FIGURE 6.4
Population density map with a higher number of classes used



6.3 CHANGING THE VALUES OF THE CLASSES

Besides changing the number of classes, as you have done in the previous exercise, it is also possible to change the values of the classes. This as you might be interested in other intervals than ArcView has assigned to the classes. Changing the values of classes can be done in a similar way as changing colours or number of classes of a legend: double click on the Theme legend, or by going via the menu: **Theme/Edit Legend**, after which the **Legend Editor** window pops up. You want to change the values of the intervals, to do this you need to type the desired values in the Value boxes. Go with the pointer to the top box under Value, where is written 11 48 (Figure 6.5). Type '0–10', and press **Enter** on your keyboard. You will notice that the values in the box under Label also changes into '0–10', and the box below (where is written 49–70) becomes active. Replace these values with '10 - 20'. Continue replacing the next values in 20–30, 30–40, etcetera. You will notice that the last class contains the values 923–1825. To display all the information of this Theme you will need to include the highest values of this Theme also. So in the last box you type '140–1825'. After you have pressed **Enter** on your keyboard you will notice that the top label in the Legend Editor becomes active. Scroll down to the last line and replace '140–1825' with '>140' (Figure 6.6). Press **Apply**, and close the **Legend Editor** window. The Theme will be displayed with the new classification. Note the legend, where what you have written in the Label box ('>140') is displayed (Figure 6.7).

FIGURE 6.5
Editing the values of the classes

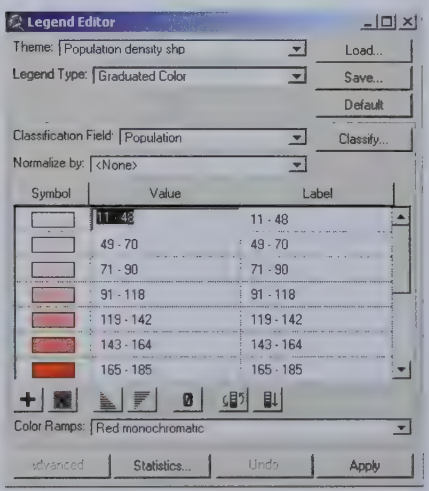


FIGURE 6.6
Changing the labels of a legend

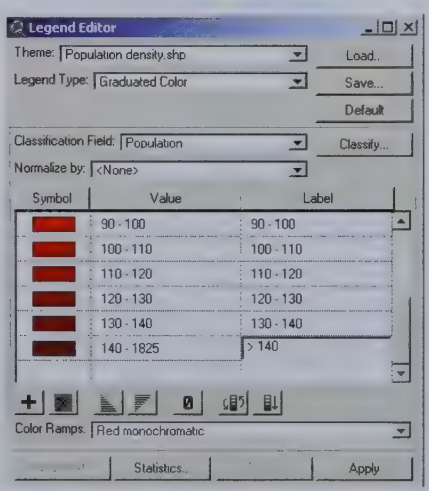
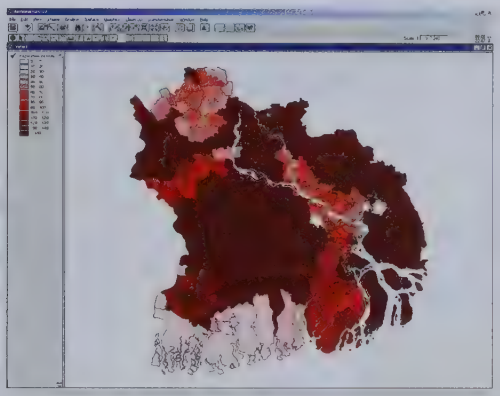


FIGURE 6.7
Changed Theme



6.4 SAVING AND LOADING OF LEGENDS

Making a new legend with new colours takes considerable time. It is possible to save a Legend once you have made it, so that you do not have to make it again when you have new data. To save the legend that you have just made, you have to open the Legend Editor window by double clicking on the Theme legend, or by going via the menu: **Theme/Edit Legend**. Click **Save...**, after which the **Save Legend** window pops up. Select an appropriate folder to save your Legend in (for instance: C:\02_graphical display) and save the legend with an appropriate name (for instance: 'population15.avl'), see Figure 6.8.

Please note that Legend files have the extension '.avl'.

The legend that was used at the beginning of the paragraph, where changing the colours of a legend was discussed, has been saved in the folder '02_Graphical display'. Try to load this Legend in your current Theme. To load a previously made legend, open the Legend Editor window (double clicking on the Theme legend, or by going via the menu: **Theme/Edit Legend**), press **Load**, go to the appropriate folder (here '02_Graphical display'), and select the needed file (here 'population density.avl', see Figure 6.9), press **OK**. The Load Legend window pops up, press again **OK**. You will see that the legend in the Legend Editor has changed to the original legend. Press **Apply** and close the **Legend Editor** window. The Theme will now display the data in the way it was displayed during the exercise on page 15. Try now to load the legend that you have just saved ('population15.avl').

FIGURE 6.8
Save Legend

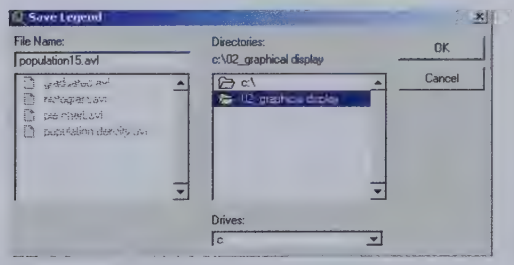
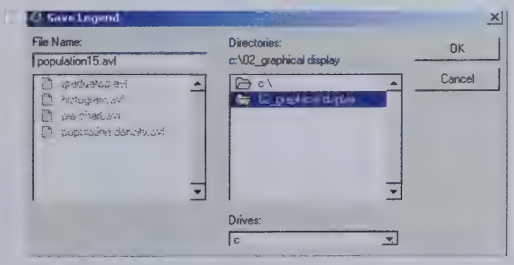


FIGURE 6.9
Load Legend



6.5 SELECTING AND APPLYING BAR OR PIE GRAPHS

Until now the data in the maps were displayed with graduated colours filling the sub-districts. However, we could prefer a different graphic display, such as histograms or pie charts. Sometimes these displays are needed if we want to display two or more parameters in the same map.

Compare these different displays. Add 'population density.shp' two more times to the View.

The type of graphical display can be changed in a similar way as changing the colours, by double clicking on the Theme Legend after which the **Legend Editor**-menu pops up. Open the Legend Type box with the arrow on the right-hand side and select **'Chart'** (Figure 6.10).

FIGURE 6.10
The menu for changing the graphical display

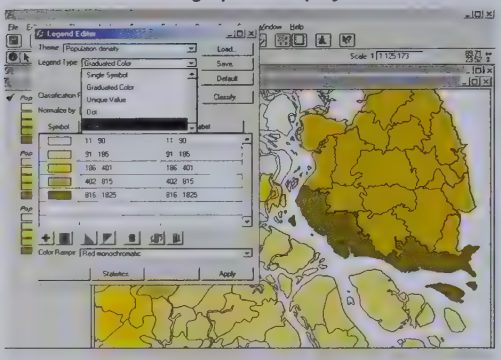
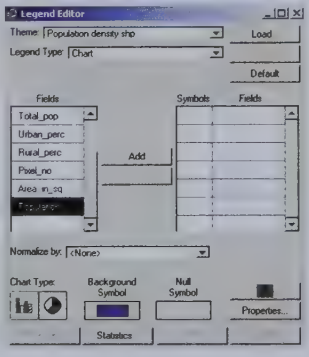


FIGURE 6.11
Adding a field or parameter for graphical display

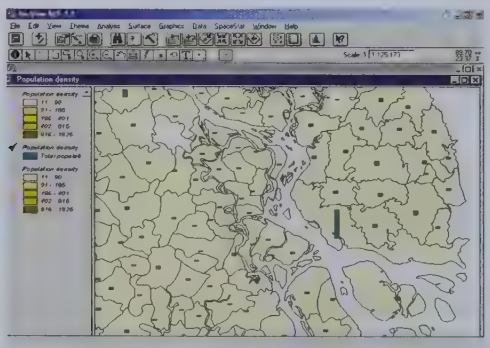


Now you see the **Legend Editor** and you have to select the **Field** or parameter you want to display (which is the population density per sub-district), select in the Fields box 'Population' (representing the population density) and click **'Add'** (Figure 6.11).

After adding 'Population', we see that this parameter appears in the right window, indicating a '**symbol**', which is the colour and the form of the displayed parameter, and a '**Field**' indicating the name of the selected parameter. Finally, you have to choose between a pie or histogram display, by clicking on the desired **Chart Type** button. Select Histogram, click **Apply**, and close the window. Automatically the data are displayed in Histogram form in Map View (Figure 6.12).

If you want to change the properties of the Histogram, i.e. colour or size, you open the **Legend Editor** again by double clicking on the **Theme Legend**.

FIGURE 6.12
Histogram presentation of the population density of Pais Pesca



For changing the colour after opening the **Legend Editor**, double-click on **Symbols** in the right window and the **Fill Palette** screen pops up (Figure 6.13). Click on the **Brush**-button in the **Fill Palette,** and the **Color Palette** (Figure 6.14) pops up. Click a colour, click **Apply**, and close all menus. Obviously, to see a Theme with the changes you have made, the View Checkbox (Figure 4.7) of that Theme should be checked.

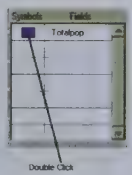
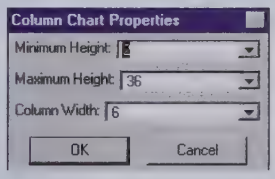


FIGURE 6.13
The Fill Palette

FIGURE 6.14
The Color Palette

For changing the style of the histogram, click in the **Legend Editor** window (after double clicking the Theme in the View table of contents, see Figure 4.11) on the **Properties** button, located below on the right side; the **Column Chart Properties** window will pop up where the height and width of the chart can be adjusted.



Try it: make a histogram of 'Total_pop', and a pie of 'Total_pop' in the two added Themes.

Note: The pie distribution of 'Total_pop' does not give valuable results. In general, pies are more suitable to visualize two or more related parameters.

Note: Make sure you are looking at the right theme! (check the view box, Figure 4.7).

After you made the histogram and pie chart, close everything and exit ArcView (you can save the project, so that you can have a look at this later on).

6.6 DISPLAYING TWO PARAMETERS IN ONE THEME

It can be that you want to display more than one parameter in one Theme, for example a set of different water-quality parameters, or income figures of different social strata. You can do this with histograms or pie charts.

Open ArcView, a New Project (via menu bar: **File/New Project**), a new View (in the project window, press the New button). Add the Theme 'District town.shp', and add the Theme 'Population density.shp' from the folder: '03_More_Parameters_in_1_Theme' in the CD. This last Theme contains, among others, socio-economic data of sub-districts in Pais Pesca. Of special interest for this exercise is the distribution between urban and rural population. Make sure the 'District town.shp' Theme is placed above the 'Population density.shp' Theme. If this is not the case, you can press the legend of 'District town.shp' with your mouse pointer, keep the mouse pressed, and move the Theme above the 'Population density.shp' Theme (in Windows terms: 'drag and drop'). Do you notice that with the 'District town.shp' under the 'Population density.shp' Theme you can not see the 'District town.shp' Theme?

FIGURE 6.15
Moving the District town.shp Theme on top

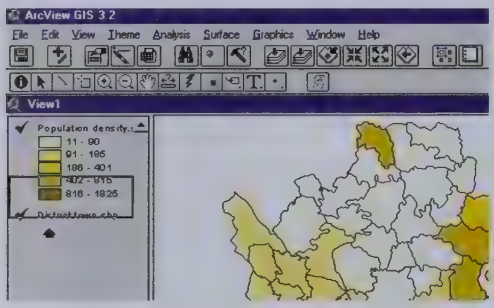
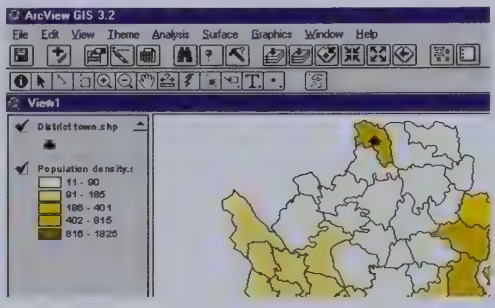
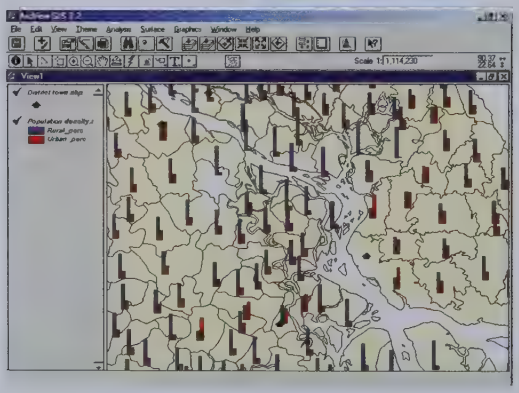


FIGURE 6.16
The District town.shp Theme on top



Double click on the **Theme Legend** of the 'Population density.shp' Theme to open the **Legend Editor**; select **Chart** in the **Legend Type** select box; select in the **Fields** box 'Rural_perc' and 'Urban_perc' (representing the percentile distribution between rural and urban in the sub-district population), and press the **Add** button. Change the colour of the histogram bars using the **Color Palette** into blue for 'Rural_perc' and red for 'Urban_perc', you might want to change the background colour to light yellow to get the same picture as in Figure 6.17. Click on **Chart Type** on the **Bar** icon, adjust when necessary the histogram properties by pressing the properties button and changing the properties in the screen that pops up, click **Apply** and close the window. The double histogram will automatically be displayed (Figure 6.17).

FIGURE 6.17
Double histogram of the percentage of urban and rural population in the different sub-districts of Pais Pesca



Note: What do you see with respect to the district towns, and the urban and rural population distribution?

Another way to display this data is the 'Pie chart'. The advantage of a Pie chart is that we can add one more parameter to the display of rural and urban population by relating the size of the pie to a third parameter in this case the total population per sub-district.

Add once more a Theme 'Population Density.shp' to the View, and select this Theme. Double click on the legend of this Theme. Select again **Chart** in the **Legend Type** box, add the fields 'Rural_perc' and 'Urban_perc', and select **Pie** with the **Chart Type** selection button.

Click on the **Properties** button; the Pie Chart Properties window will pop up (Figure 6.18).

Set the maximum and minimum size of the pie to 4 and 26, respectively, and select 'Total_pop' (representing the total population per sub-district) in the size field select box to relate the size of the pie to the population density of each sub-district. Use the

same colour scheme as with the histograms (rural blue, urban red, background yellow). Click **OK** and **Apply** and the pie chart will be displayed (Figure 6.19). Close the project and exit ArcView.

FIGURE 6.18
Setting the properties of a pie chart

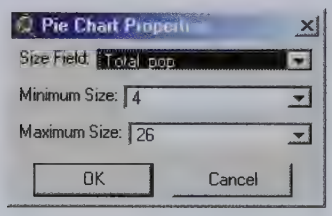
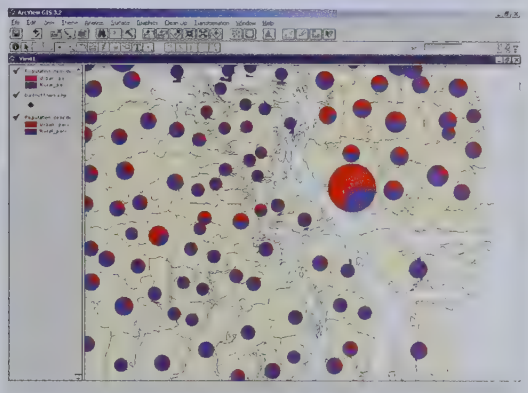


FIGURE 6.19
Rural and urban population displayed in combination with the total population in each district



6.6.1 Riverine frame survey of Pais Pesca

In 1998, the Department of Fisheries of Pais Pesca carried out a frame survey on inland fishers in all district of the country. All professional fishers of Pais Pesca were registered, i.e. people who get their main income from fisheries. Furthermore, all boats (large and small) were registered, and information on the annual income (US$/year) of the large boat owners/fishers, small boat owners, and fishers without a boat was collected. All data were digitized and linked with an ArcView Theme file: 'Inland_frame_survey.shp'.

Open ArcView, a New Project, and a New View. Add the Theme 'Inland_frame_survey.shp' (from the folder: '04_Riverine_Frame_survey' on the CD) to the View.

Use this file to make:

1. A graduated colour display of the total number of fishers as a percentage of the total population ('PERC_FISH').
2. A histogram chart of the total number of fishers as a percentage of the total population ('PERC_FISH').
3. A histogram chart with total population ('TOTAL_POP') and total number of fishers ('TOTAL_FISH').
4. A histogram chart with fishers with boat ('WITH_BOAT'), and fishers without boat ('WITHOUTBOA').
5. A pie chart with fishers with boat, fishers without boat and the pie size related to the total number of fishers (minimum size 4, maximum size 26).
6. A pie chart with the number of large boats ('LARGE_BOAT'), the number of small boats ('SMALL_BOAT') and the pie size related to the total number of boats ('TOTAL_BOAT').
7. A histogram chart with the income of large boat owners ('INCOME_LAR'), small boat owners ('INCOME_SMALL') and the income of fishing labourers ('INCOME_FIS').
8. A pie chart with the income of large boat owners, income of small boat owners, and income of fishing labourers, with the pie size related to the income of fishing labourer.

Note: Sometimes the background colour of Pais Pesca in the created display is not convenient. You can change this by clicking on **Background Color: Select Color** button in the View Properties box (via the menu: **View/Properties**) and then select a convenient colour in the Color Picker box.

7 Views and Themes: definitions and characteristics

In the previous chapters we have seen that Views are interactive maps to show Themes that represent real objects having a geographic location and a representative shape (like a district, a sub-district, a town).

ArcView can work with three types of data sets:

- Shapefiles, which represent a geographical location. Data in the form of a table can be linked to these.
- Grid files, which already contain data in the form of a raster of pixels whereby each pixel represents a certain value – the parameter represented by the Grid.
- Images files[4], for images obtained from, for example, satellites.

The different characteristics of data sets determine the way they can be used in GIS and set the limits of their use in different types of analyses. Therefore, they are discussed more in detail in the next chapter.

There are in principle three different types of shapefiles:

- Polygon features, which are closed figures, enclosing a certain area and can represent a country, district, lake, forest, etc.
- Point features, indicating an exact location (of tube wells, schools, villages, etc).
- Line features, indicating the location, length and direction of for instance rivers, roads, canals, etc.

Basically, Point and Line features have no area, but are related to locations, while Polygon features always have a location and an area.

[4] Not further discussed in this manual.

8 Joining data with location on a map

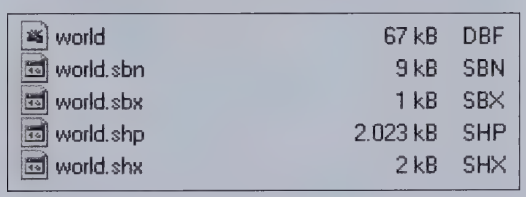
One of the basic principles of GIS we must keep always in mind: **We join data, stored in a table, with a location on a map, representing a location on Earth.**

In the exercises given in the previous chapters, data were already joined to the different Themes used. In this chapter, we explain how to join data in ArcView with locations in Maps or Themes.

First a short explanation on the different files used by ArcView software. A Theme consists of several files (Figure 8.1), mostly files with the extensions '.sbn', '.sbx', '.shp', '.shx', and '.dbf'. If you want to put a Theme on a floppy disk, you have to copy all files to be able to display the Theme on another PC. ArcView shapefiles are a simple, non-topological format for storing the geometric location and attribute information of geographic features. A shapefile is one of the spatial data formats that you can work with in ArcView. The shapefile format defines the geometry and attributes of geographically-referenced features in as many as five files with specific file extensions that should be stored in the same project workspace. They are:

- '.shp' – the file that stores the feature geometry.
- '.shx' – the file that stores the index of the feature geometry.
- '.dbf' – the dBASE file that stores the attribute information of features. When a shapefile is added as a theme to a view, this file is displayed as a feature table.
- '.sbn' and '.sbx' – the files that store the spatial index of the features. These two files may not exist until you perform theme on theme selection, spatial join, or create an index on a theme's Shape field. If you have write access to the source data directory, the index files will be persistent and remain after your ArcView session is complete. If you do not have write access to the source data directory, they will be removed when you close the project or exit ArcView.
- '.ain' and '.aih' – the files that store the attribute index of the active fields in a table or a theme's attribute table. These two files may not exist until you perform Link on the tables. If you have write access to the source data directory, the index files will be persistent and remain after your ArcView session is complete. If you do not have write access to the source data directory, they will be removed when you close the project or exit ArcView.

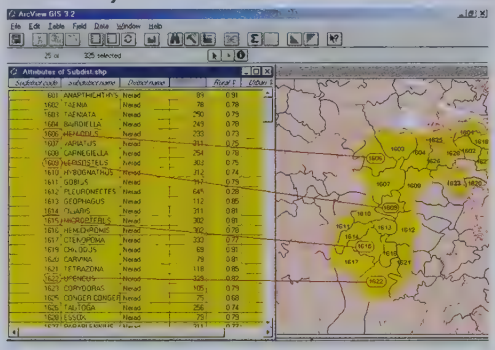
FIGURE 8.1
The different files making a shapefile in ArcView



Now that you know a bit more about the different files that are used in ArcView joining will be discussed: the basic principle of joining is that the data obtained from a certain location is stored in a Table that contains a code number or name of the specific location. When two or more Theme files contain exactly the same code or name it is possible to join the files through this code.

Have a look at the following example; below in Figure 8.2 a table with data of different sub-districts in the Nerad district is presented together with a polygon shapefile of the same sub-districts.

FIGURE 8.2
Data table and map of the sub-districts in Nerad districts, both indicating the codes used to join the data with the location of the sub-district



In the polygon shapefile as well as in the table, you can see the codes (numbers) through which the two were joined. Have a look below on how the two (a table and a polygon file) can be joined in ArcView.

8.1 JOINING A TABLE WITH A POLYGON FILE

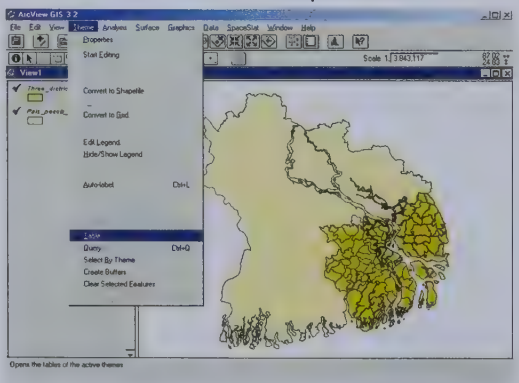
Adding two Themes

Start ArcView, start a New project, and open a New View. Add the Themes 'Pais pesca country.shp' and 'Three districts.shp' (from the folder '05_joining_Table_and_Polygon').

Viewing the Theme table

The contents of a shapefile or the Theme table can be viewed by either clicking on the **Open Theme Table** icon or via the menu bar: **Theme/Table.**

FIGURE 8.3
View contents of a shapefile table



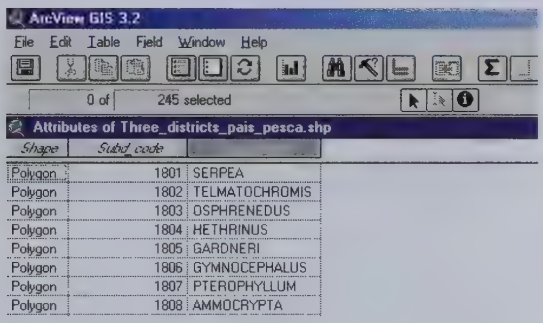
If we open the Theme table of 'Pais_pesca_country.shp' (Table 8.1), we see the following data attached:

TABLE 8.1
Sample data of theme table for 'Pais_pesca_country.shp'

Shape	Population	Sqr_km	Total_pop	Rural_perc	Urban_perc
Polygon	253	90 442	2 301 1601	77	23

If we open the theme table of the 'Three_districts_pais_pesca.shp' Theme we see that the table only contains the fields: 'Shape', 'Subd_code', and 'Subd_name' (Figure 8.4).

FIGURE 8.4
The Theme table of 'Three_districts'-shapefile with sub-districts codes and names



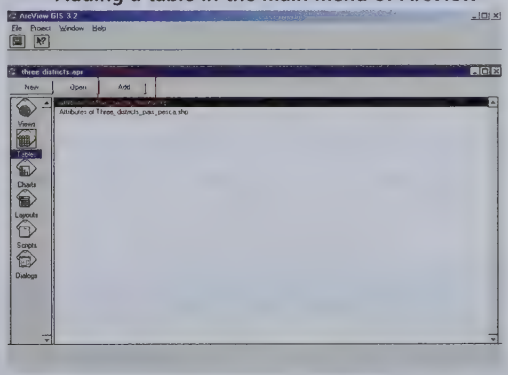
Shape	Subd_code	
Polygon	1801	SERPEA
Polygon	1802	TELMATOCHROMIS
Polygon	1803	OSPHRENEDUS
Polygon	1804	HETHRINUS
Polygon	1805	GARDNERI
Polygon	1806	GYMNOCEPHALUS
Polygon	1807	PTEROPHYLLUM
Polygon	1808	AMMOCRYPTA

Close the table and close the View through '**x**' or via the menu bar: **File/Close All**.

Adding a Table

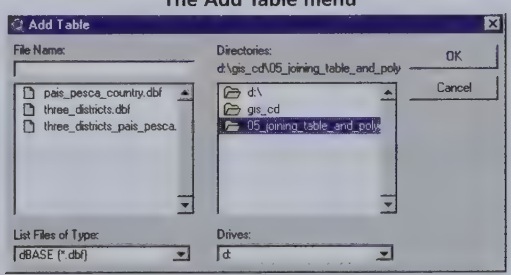
You are back at the project window of ArcView. Make sure the **Tables** window is the active window, by clicking the **Tables** icon in the project window once (Figure 8.5).

FIGURE 8.5
Adding a table in the main menu of ArcView



To add a Table you click on the **Add** button on top of the Tables window and the **Add Table** window will appear (Figure 8.6).

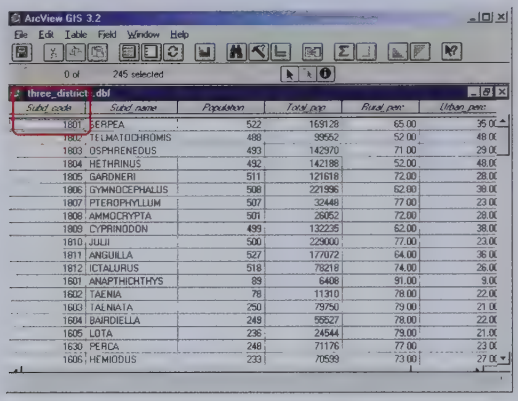
FIGURE 8.6
The Add Table menu



Select in the Drives select box the drive where you have the CD, or where you have copied the files, go to the '05_Joining_Table_and_Polygon' folder, select in 'List of File Type:' **'Dbase files (*.dbf)'**, and finally, select in the File Name select box 'three_districts.dbf' and Click **OK**.

The table will be added to the project and will be opened. You will see that the first field heading in the table is 'Subd_code' (Figure 8.7). With this field you will be able to join both this table and the Theme 'Three_districts_pais_pesca.shp', as the Theme has the same number linked to a sub-district in the field: 'Subd_code'.

FIGURE 8.7
The added table of 'Three_districts' with the sub-districts codes and data



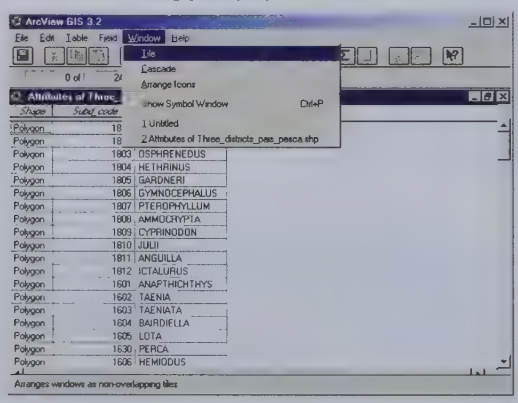
Joining the Table with the Theme's attribute table

You want to join the data from 'Three_districts.dbf' with the 'Attributes of Three_districts_pais_pesca.shp' table. For this you need to use the sub-district codes that are identical in both files.

Joining a **Table** with a **Theme's** attribute table file is always carried out in the same five steps:

1. Open 'Attributes of Three_districts_pais_pesca.shp'. Once it is open click on **'Windows/Tile'** in the menu bar (Figure 8.8). You will see that the project window is nicely placed next to the opened attribute table.

FIGURE 8.8
Tiling your project window

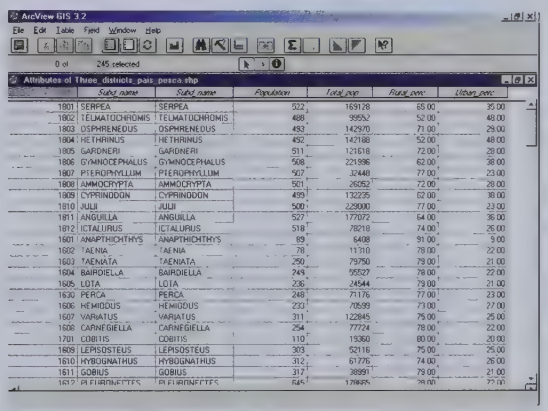


2. Open 'Three_district.dbf' and Tile the project window again and the results are that the two tables and the project window are nicely arranged next to each other, and you can start joining the two.
3. Select 'Subd_code' by pressing the header with your mouse pointer in the 'Three_districts.dbf' table, the table from which you take the data, or the **source table**. After clicking on 'Subd_code', you see that this column header becomes darker than the rest of the headers.

4. Select the header of the field 'Subd_code' in the 'Attributes of Three_districts_pais_pesca.shp', the table you want to bring the data to, or the **destination table**. Also here, after clicking on the header, it becomes darker than the rest of the headers.
5. After having selected the two column headers, the **Join Table** button becomes visible. Click this button and the data from the source table will be joined with the destination table, the source table will disappear.

Maximize the table 'Attributes of Three_districts_pais-pesca.shp' and you will see that the data are added (Figure 8.9). When you have done the complete exercise, you can close the project, and exit ArcView.

FIGURE 8.9
Attribute table with the joined data


ArcView GIS 3.2
File Edit Table Field Window Help
0 of 245 selected
Attributes of Three_districts_pais_pesca.shp
Subd_name
Subd_name
Population
Total_pop
Rural_perc
Urban_perc
1801 SERPEA SERPEA 522 169128 65.00 35.00
1802 TELMATOCHROMIS TELMATOCHROMIS 488 99552 52.00 48.00
1803 OSPHRENEUS OSPHRENEUS 493 142970 71.00 29.00
1804 HETHRINUS HETHRINUS 452 142188 52.00 48.00
1805 GARDINERI GARDINERI 511 121618 72.00 28.00
1806 GYMNOCEPHALUS GYMNOCEPHALUS 508 221996 62.00 38.00
1807 PTEROPHYLLUM PTEROPHYLLUM 507 32448 77.00 23.00
1808 AMMOCRYPTA AMMOCRYPTA 501 26052 72.00 28.00
1809 CYPRINODON CYPRINODON 499 132235 62.00 38.00
1810 JULII JULII 500 229000 77.00 23.00
1811 ANGUILLA ANGUILLA 527 177072 64.00 36.00
1812 ICTALURUS ICTALURUS 518 78218 74.00 26.00
1601 ANAPTHICHTHYS ANAPTHICHTHYS 89 6408 91.00 9.00
1602 TAENIA TAENIA 78 11310 78.00 22.00
1603 TAENIATA TAENIATA 250 79750 79.00 21.00
1604 BAIRDIELLA BAIRDIELLA 249 55527 78.00 22.00
1605 LOTA LOTA 236 24544 79.00 21.00
1630 PERCA PERCA 248 71176 77.00 23.00
1606 HEMIODUS HEMIODUS 233 70599 73.00 27.00
1607 VARIATUS VARIATUS 311 122845 75.00 25.00
1608 CARNEGIELLA CARNEGIELLA 254 77724 78.00 22.00
1701 COBITIS COBITIS 110 19360 80.00 20.00
1609 LEPISOSTEUS LEPISOSTEUS 303 52116 75.00 25.00
1610 HYBOGNATHUS HYBOGNATHUS 312 61776 74.00 26.00
1611 GOBIUS GOBIUS 317 38991 79.00 21.00

Note:

Try to remember the small phrase 'DATA FIRST'. First click the code in the 'source table', the table which contains the data you want to join.

Note:

Sometimes you may think you did everything correctly and the join-icon does not appear. It could be that the joining codes do not have the same format. For example in your table file the code has a 'text format', and in the shapefile the code has a 'numeric format'. Then joining is not possible.

Note:

ArcView can not import a spreadsheet file (be it from Lotus 1–2–3, MS Excel, QuattroPro, etc). If your data are stored in an MS Excel file, you can either run ArcView's SQL connection to retrieve your data, or you try to save your data as a '.dbf' file which is accessable by ArcView. More detailed information is provided in Annex B, ArcView and Microsoft Excel.

8.2 JOINING FISH CATCH DATA OF THE DISTRICTS WITH A POLYGON SHAPEFILE

Through a Catch and Effort recording and a habitat oriented fish catch monitoring system the Department of Fisheries of Pais Pesca estimates every year the annual fish catch of each district, the annual catch per fishers (CPUE) and the distribution of the catch over four major groups: Migratory species, Brackishwater species, Prawns, and Others. The results of 2001 are presented in Table 8.2.

TABLE 8.2
Fisheries data Pais Pesca of 2001

DIST_CODE	DIST_NAME	CATCH *(metric tonnes/ year)*	CPUE *(metric tonnes/ fishers/year)*	MIGRATORY *(metric tonnes/ year)*	PRAWNS *(metric tonnes/ year)*	BRACKISH *(metric tonnes/ year)*	OTHERS *(metric tonnes/ year)*
1	Denaida	181	0,600	18	9	0	154
2	Ganjpani	25 750	0,600	3 090	1 802	0	20 858
3	Cankir	139 943	1,080	30 787	16 793	0	92 362
4	Kathijalo	32 201	0,600	3 542	2 576	0	26 083
5	Dadon	75 900	0,830	18 975	10 626	0	46 299
6	Grumara	252 900	0,850	20 232	37 935	0	194 733
7	Pepedas	109 000	1,360	25 070	14 170	0	69 760
8	Felixsad	94 300	0,790	7 544	7 544	0	79 212
9	Bandarbadan	182 570	1,280	16 431	16 431	0	149 707
10	Muladi	45 702	0,880	914	0	2 742	42 046
11	Siraba	105 500	0,860	3 165	1 055	18 990	82 290
12	Faodoa	130 000	0,880	2 600	2 600	27 300	97 500
13	Boldan	93 780	0,920	3 751	938	18 756	70 335
14	Bargun	39 470	0,790	1 184	789	7 499	29 997
15	Puradi	54 600	0,950	1 092	1 092	11 466	40 950
16	Nerad	141 000	1,300	2 820	9 870	9 870	118 440
17	Goodt	396 580	1,810	19 829	3 966	91 213	281 572
18	Tara	30 200	0,660	302	604	0	29 294

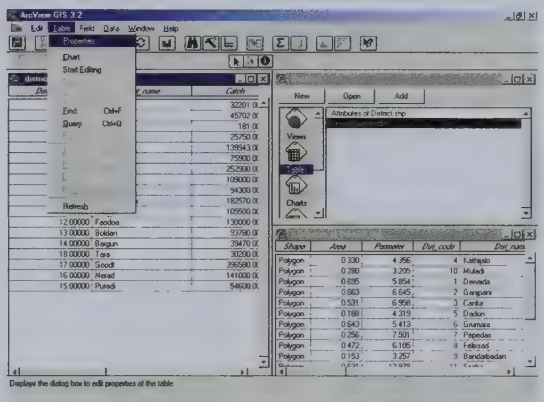
The data are stored in a .dbf file ('district_catch.dbf') in the '06_Catch_Data_with_Theme' folder on the CD.

1. Join the data with the 'District.shp' Theme (also to be found in the '06_Catch_Data_with_Theme' folder in the CD, you first have to start ArcView, add this Theme, etc., of course).
2. Make a multiple pie chart with 'Migratory catch', 'Prawns', 'Brackishwater species', and 'Others' with the pie size related to CPUE. Remember: data first!
3. If you tried to make a multiple pie chart, and you do not see the parameters mentioned before (Migratory catch, Prawns, etc.) in the Legend Editor after having selected 'Chart' as the Legend Type, you probably have used the 'Attributes of district.shp' as the source table when joining. Start over again, and now joining the two tables the other way around: after tiling both tables ('Attributes of district.shp' and 'district_catch.dbf'), first press the correct field heading of the source table, which in this case is...?[5].

After you have joined the two tables you will see that the **District name** appears two times in the new attribute table, this is annoying and will become even more annoying if you add more data and the **District name** appears several times. This can be avoided by deselecting **District name** in the source table 'district_catch.dbf' before executing the **join;** when the two tables are opened, select the source table and go via the menu bar (**Table/Properties**) (Figure 8.10) to the Table properties.

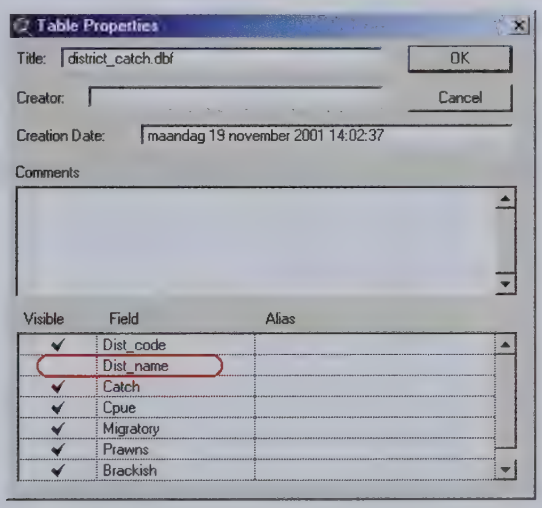
[5] 'district_catch.shp'.

FIGURE 8.10
Selecting the Table Properties



In the **Table Properties** window uncheck the Field(s) you want to hide and do not want to join (Figure 8.11), after which you click **OK** and continue with joining as explained before.

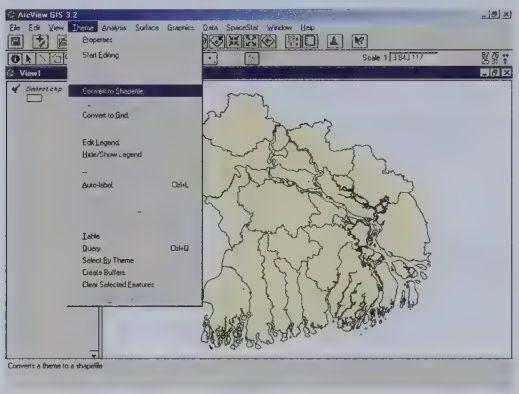
FIGURE 8.11
Changing the Table Properties



Joining two tables does not change the actual tables, i.e. the changes are not permanently stored in the Theme's attribute table. Once you have saved everything as a project and open this project again, ArcView will make the join again. It also means that if you open the 'District.shp' file in another project, the **join** will not be visible. The **join** will not be made again if you remove the 'district_catch.dbf" file, or place it in another sub-directory. To add the data permanently to the Theme, the easiest way is to convert the Theme (with the new **join**), to a new Theme:

1. After joining the tables, open **View** again and activate the **Theme** you want to convert by clicking with the mouse pointer on the legend of the Theme.
2. Select **Theme/Convert to Shapefile** from the menu bar (Figure 8.12).

FIGURE 8.12
Converting to a shapefile



3. The **Convert Theme** select box will popup. You need to select the folder where you want to save the new shapefile, give it a new name: 'Dist_catch' and click **OK.**
4. You will get the question '**Add shapefile as theme to view?**', click **Yes**.

A second option is to save the new table separately in a new .dbf file.

5. Open the **Attribute table** of the Theme involved.
6. Go to: **File/Export** in the menu bar, the **Export Table** select box will pop up, select **dBase**, click **OK.**
7. In the new **Export Table** window select a folder where you want to save the file, give the file a new name, and click **OK**.

9 How to edit your Theme table and do calculations

If you work with large data sets, the easiest way to manipulate your data is to use spreadsheets or Dbase programs and join this data with the attribute theme tables. However, if your Attribute Theme table does not contain so many records it is easy to add data and carry out simple manipulation directly in the Attribute table while working in ArcView.

An Example:

The price of prawns is not the same all over the Pais Pesca, it depends on the location of the market. Higher prices are paid close to the industrial zones and major cities. Average prices of different districts are presented in Table 9.1.

TABLE 9.1
Prawn prices per district (2001)

District Name	Prawn price *(US$/kg)*
Kathijalo	1.10
Muladi	1.10
Denaida	0.90
Ganjpani	1.20
Cankir	1.80
Dadon	2.10
Grumara	2.30
Pepedas	2.70
Felixsad	2.50
Bandarbadan	2.60
Siraba	0.90
Faodoa	1.20
Boldan	0.90
Bargun	1.30
Tara	3.10
Goodt	1.60
Nerad	2.00
Puradi	1.20

The instructions below will show you how to Add these prices to the district Theme where you joined the fish catches and Add a new field with the total value of prawns per district.

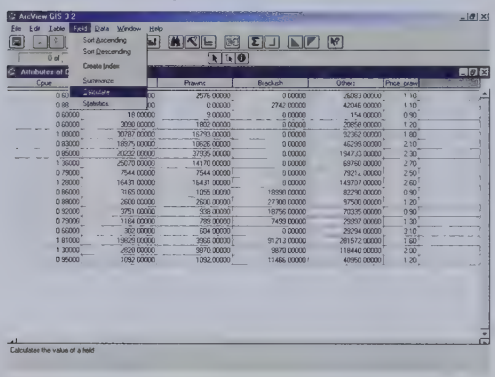
9.1 ADDING A FIELD AND MAKING CALCULATIONS IN A TABLE

Start a new project and open a new View.

1. Add the Theme you saved previously ('Dist_catch.shp'). If you can not find it, you can find it in the folder '07_Them_Table_calculation_and_edit' in the CD. Remember the remark made previously on the Read only protection of files copied from a CD: "...When you copy files from a CD onto your hard disk, these files will have the properties as Archive and Read only. To be able to work with the files, you will need to change the properties of the files you use: open the Windows Explorer, right-click on the file(s) you copied and are going to use, click properties, and look in the General tab under Attributes (at the bottom). All tick boxes need to be empty. If one of the boxes is ticked, untick it, so that the files can be edited...".

2. Click on the **Open Theme Table** button and select via the menu bar: **Table/Start Editing**.
3. Go via the menu bar to: **Edit/Add Field**.
4. The **Field Definition** box will pop up. Put 'Prawn price' in the **Name:** box. In the **Type:** box there has to be **Number**, as numeric data will be entered. Further you see **Width:** where **16** is given as default. This is the number of characters which can be entered, change this to **5**. Finally in the last box (**Decimal Places:**) put **2**. Click **OK.**
5. An error message will appear: 'Field name too long. ArcView will truncate field name and use original name as Alias. Continue?', Click **Yes.**
6. Before entering data in the new column you have to click on the **Edit** icon in the Tool bar. Click now with the pointer on the cell where you want to enter the data. Enter the data and select the next cell, etc.
7. When you have finished entering data you need to add a new field: **Value Prawns**, (in the field definition box: leave the default number (16) and no decimals). After you click **OK** you will get again a message that the name is too long. Continue and click **Yes.**
8. Make sure the **Value Prawns** field heading is 'pressed' (darker, and the letters are in white) before you continue, to make sure that the calculation that follows ends up in the **Value Prawns** field.
9. The value of the prawns for each district we calculate in ArcView. Go to: **Field/Calculate...** via the menu bar (Figure 9.1).

FIGURE 9.1
How to get to the Field Calculator



10. The Field Calculator window will pop-up. We know that the Value of the prawns equals Catch of prawns times Price of prawns. This is what you need to enter in the box on the bottom. First double click on **[Prawns]** in the **Fields:** box on the left (Figure 9.2). You will see **[Prawns]** appear in the calculation box.

FIGURE 9.2
The Field Calulator window

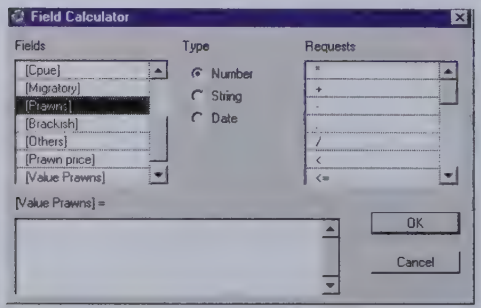
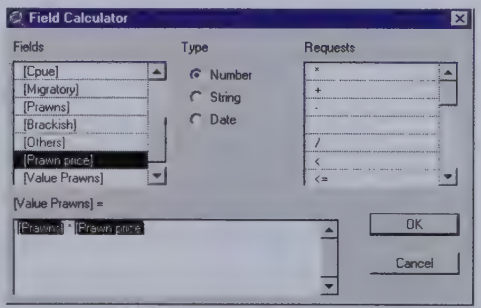


FIGURE 9.3
The Field Calculator window filled in



11. Now double click in the 'Request box' on '*', as you want to multiply. After this, double click in the **Fields:** box on **[Prawn price]**.
12, The calculation box at the bottom now indicates the following calculation: **[Value prawns] = [prawns] * [Price prawns]** (Figure 9.3). Click **OK** and the values are calculated.
13. Go to **Table/Stop Editing** in the menu bar, when you are asked: 'Save Edits?', click 'Yes'.

Now make a double histogram with prawn catch and prawn value, using the Legend Editor.

10 Difference between Polygons and Points

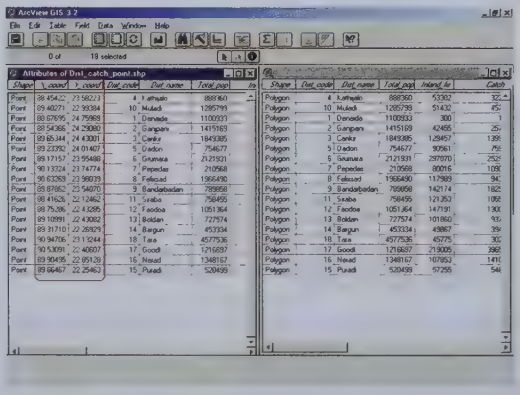
Till now we used polygon shapefiles, i.e. shapefiles that enclose a certain geographical area on a map. Another type of shapefile, often used, is a point shapefile. We explain the differences between the two with the following exercise.

10.1 DIFFERENCE BETWEEN POLYGON AND POINT SHAPEFILES

1. Start ArcView, Open a New Project, and Open a New View. Add the Themes 'Dist_catch_point.shp' and 'Dist_catch.shp' from the folder: '08_Point_vs_Polygon' in the CD.
2. Open the two attribute tables of the Themes. You can see that exactly the same data are attached in these two separate tables (Figure 10.1). Still the characteristics of the two Themes are quite distinct.
3. Make a 'Graduated Colour' distribution of the 'CPUE' for both Themes. What do you see? (If you forgot how to do this, have a look at: Displaying two parameters in one Theme, page 19).
4. Make a multiple pie chart with 'Migratory', 'Prawns', 'Brackishwater species', and 'Others' with the pie size related to CPUE for both Themes. What do you see?

From the exercises we can conclude that the main characteristic of a Point is that it is related to an exact location on a map. The exact location of each data point is indicated by the X and Y coordinates in the attribute table of Catch_dist_point.shp (Figure 10.1).

FIGURE 10.1
Two Attribute Tables



Further we have seen that most types of displaying data of these different Themes are similar.

11 Points and degrees

11.1 THE GEOGRAPHIC COORDINATE SYSTEM

A key geographical question throughout the human experience has been: "Where am I?". In classical Greece and China, attempts were made to create logical grid systems of the world to answer this question. The ancient Greek geographer Ptolmey created a grid system and listed the coordinates for places throughout the known world in his book Geography. But it was not until the middle ages that the latitude and longitude system was developed and implemented. This system is written in degrees (°).

When looking at a map, latitude lines run horizontally. They are also known as parallels since they are parallel and are at equal distant from each other. Each degree of latitude is approximately 111 km apart. Degrees latitude are numbered from 0° to 90°. Latitude 0° corresponds to the Equator, the imaginary line which divides our planet into the Northern and Southern hemispheres. Latitudes 90° and -90° refer to the North Pole and the South Pole respectively.

The vertical longitude lines are also known as meridians. They converge at the poles and are widest at the Equator. Longitude 0° is located at Greenwich, England. The degrees continue 180° (or 180° east) and -180° (or 180° west) where they meet and form the International Date Line in the Pacific Ocean. Greenwich, the site of the British Royal Greenwich Observatory, was established as the site of the Prime Meridian by an international conference in 1884.

There are two methods of expressing fractions of degrees. The first method divides each degree into 60 minutes (1° = 60'), then each minute into 60 seconds (1' = 60"). This system is called DMS (degrees, minutes, seconds). The symbol for degrees is ° , for minutes is ', and for seconds is ". For example Rome, Italy is located at the latitude 41° 53' 00", longitude 12° 30' 00". The second method states the fraction as a decimal of a degree. This is the DD (decimal degree) system. With this system the position of Rome is: latitude 41.88333°, longitude 12.5°.

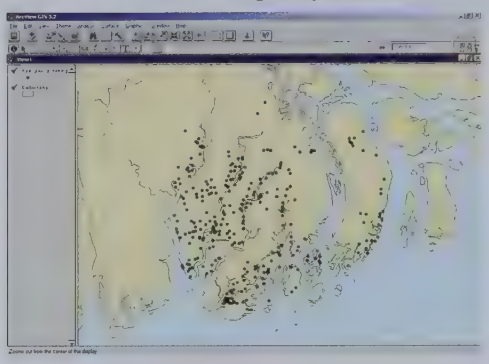
To convert from the DMS system to decimal degrees (DD) you can use a simple formula: (degrees)+(minutes/60)+(seconds/3600) = decimal degrees.

The conversion from DD to DMS is a little more complicated, and will be explained with the following example. Suppose you have the decimal degree reading of 5.23456°. To convert it to the DMS system, you first subtract the whole degree. 5° is the whole degree, so 5.23456°-5°=0.23456°. Then you multiply the remaining fraction with 60 minutes (0.23456° * 60'=14.0736'), 14' is the whole minutes. After this you multiply the fraction of the minutes with 60 seconds (14.0736'-14'=0.0736', 0.0736'*60"=4.416"), 4.416" are the remaining seconds. The DMS version of 5.23456° is 5° 14' 4.416"

11.1.1 Working with latitude - longitude

1. Open ArcView, a new Project, and a new View. Add from the folder '09_Degrees' the **Themes** 'Pais_pesca_fishing_villages.shp' and 'district.shp' to the **View**.
2. Change the background colour (menu bar: **View/Properties.../Select color**) to blue. **Zoom in** on the southeastern part of the **View**, until you have almost the same view as in Figure 11.1. **Autolabel** the villages Theme with 'Name'.

FIGURE 11.1
Marine fishing villages



When you move the pointer over the **View**, you will see that in the upper right corner some numbers are changing. These numbers indicate the location on the map in decimal degrees. With these numbers every point in the **View** is georeferenced: they represent an exact location somewhere on the surface of the Earth. If you look at the map, and move the pointer over the villages named Lais and Cambarellus, you will see that in the upper right hand corner the values are: (for Lais) X:90.49 and Y:22.16, and (for Cambarellus) X:90.69 and Y:22.04. In the attributes table of the villages theme these decimal degrees are even more precise:

TABLE 11.1
Location of villages in decimal degrees

	X_coord	Y_coord	DMS Longitude	DMS Latitude
Lais	90.48827	22.15964		
Cambarellus	90.68600	22.03698		

Can you calculate in Excel or on a calculator from the above decimal degrees the DMS longitude and latitude values of both villages?

The other way around is also possible. Suppose you have collected data in a village, and you want to put them in your GIS database. You know the latitude–longitude position (in the DMS system), because you have read that from a map, or from a GPS (Global Positioning System) reader. How do you convert these values to decimal degrees, so that you can use them in a GIS. Calculate the decimal degrees of the following position in the DMS system:

TABLE 11.2
Decimal degree conversion to DMS exercise

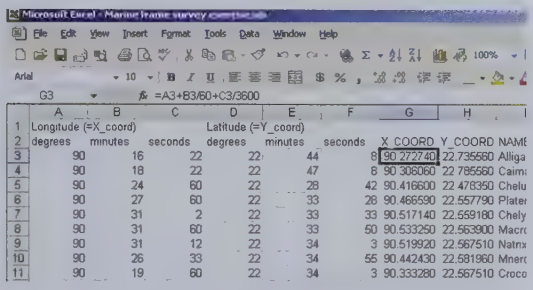
	Latitude	Longitude
DMS	22° 10′ 1.38″	90° 8′ 32.352″
Decimal Degrees		

Find the village that belongs to this position in the **View** by moving the pointer (it is best to use the **Identify** pointer, and **Zoom** in or out when needed), and looking at the numbers in the upper right hand corner. What is the name of this village? (it should be Astacus). Close the project and Exit ArcView.

11.2 PUTTING FIELD DATA INTO A GIS

In 2000 the Department of Fisheries carried out a survey in the coastal district of Pais Pesca. The objective was to locate the villages where marine fishers were living and to collect socio-economic data. You can find these data in the Excel file: 'Marine frame survey exercise.xls' in the '09_Degrees' folder. Open this file (in Excel of course!) (Figure 11.2).

FIGURE 11.2
Excel file with data of the survey of the coastal district

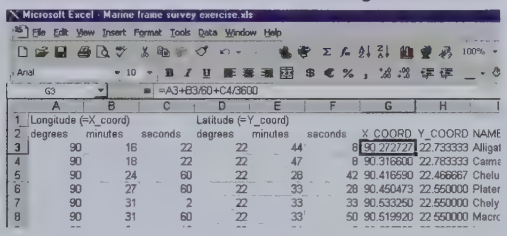


	A	B	C	D	E	F	G	H	I
1	Longitude (=X_coord)			Latitude (=Y_coord)					
2	degrees	minutes	seconds	degrees	minutes	seconds	X_COORD	Y_COORD	NAME
3	90	16	22	22	44	8	90.272740	22.735560	Alliga
4	90	18	22	22	47	8	90.308060	22.785560	Cairn
5	90	24	60	22	28	42	90.416600	22.478350	Chelu
6	90	27	60	22	33	28	90.466590	22.557790	Plater
7	90	31	2	22	33	33	90.517140	22.559180	Chely
8	90	31	60	22	33	50	90.533250	22.563900	Macrc
9	90	31	12	22	34	3	90.519920	22.567510	Natrix
10	90	26	33	22	34	55	90.442430	22.581960	Mnerc
11	90	19	60	22	34	3	90.333280	22.567510	Croco

You can see that the file contains GPS readings with degrees, minutes, and seconds in separate cells. Following these are two columns where decimal degrees are supposed to come, filled with question marks. These two columns are followed by columns with data concerning the villages. First you have to convert the GPS readings (in the DMS system) into decimal degrees (DD).

1. Convert the GPS readings into Decimal degrees on the Excel sheet. (Remember the formula?: (degrees)+(minutes/60)+(seconds/3600) = decimal degrees, see Figure 11.3).

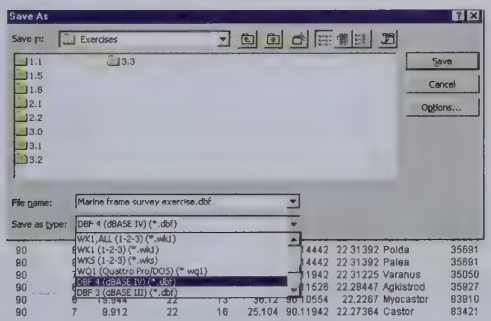
FIGURE 11.3
Excel sheet with converted GPS readings (DMS to DD)



	A	B	C	D	E	F	G	H	I
1	Longitude (=X_coord)			Latitude (=Y_coord)					
2	degrees	minutes	seconds	degrees	minutes	seconds	X_COORD	Y_COORD	NAME
3	90	16	22	22	44	8	90.272727	22.733333	Alligat
4	90	18	22	22	47	8	90.316600	22.783333	Cairna
5	90	24	60	22	28	42	90.416590	22.466667	Chelu
6	90	27	60	22	33	28	90.450473	22.550000	Plater
7	90	31	2	22	33	33	90.533250	22.550000	Chely
8	90	31	60	22	33	50	90.519920	22.550000	Macrc

2. Now the sheet is almost ready to be used in ArcView. ArcView unfortunately does not use Excel files, but does use '.dbf' files, so you have to convert the sheet that you have created into a .dbf file. Go via the Excel menu bar to: **File/Save As...**. The **Save As** screen pops up, where you change the file into a '.dbf' file (Figure 11.4). Make sure that before you save this file as a '.dbf' file, the format of the cells containing the decimal degrees (X_COORD and Y_COORD) is: **Number** with at least six decimals (select the cells, then via menu bar: **Format/Cells...**, etc.).

FIGURE 11.4
Excel sheet converted to .dbf file

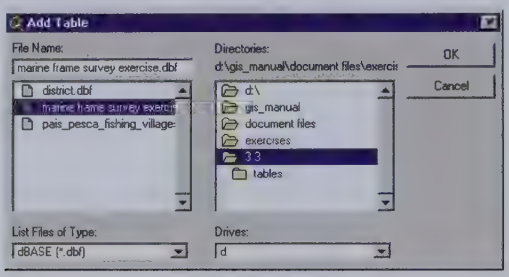


3. When you save the sheet as a '.dbf' file, you will get the message starting with: 'The selected file type does not support workbooks that contain multiple sheets'. Because you are only interested in the active sheet click **OK**. You have now

exported the Excel file in a format that you can use in ArcView. You will now be able to import the data and use them into the **View** you have of Pais Pesca. For more information on working with Microsoft Excel and ArcView, have a look at Annex B: ArcView and Microsoft Excel on page 150.

4. Open ArcView, Open a New Project, Open a New View, and add the **Theme** 'district.shp' to the **View.** Close the **View**, go to **Tables** and press **Add.** Look for the file you just have created ('Marine frame survey exercise.dbf') and press **OK** (Figure 11.5).

FIGURE 11.5
Importing the 'Marine frame survey exercise.dbf' file



5. Open the table and make sure the data are still correct. Pay special attention that in the field X_COORD and Y_COORD you have values with six decimals. If this is not the case, you have to do the conversion from Excel sheet to '.dbf' file again, but now pay attention that the cells containing the decimal degrees (X_COORD and Y_COORD) have a number format, with 6 decimals. Maybe you also have to Copy the cells and Paste special (value) them.
6. If the data look okay, close the table and go to **Views.** Open the **View**. Now you want to add the data to this **View** (where the district theme is already present). Go via the menu bar to: **View/Add Event Theme...** (Figure 11.6).
7. The **Add Event** window will pop up. Here you have to insert which file you want to add ('Marine frame survey exercise. dbf'), and which fields contain the X and Y coordinates (X_COORD and Y_COORD) (Figure 11.7).

FIGURE 11.6
Adding a theme with collected data from the marine frame survey

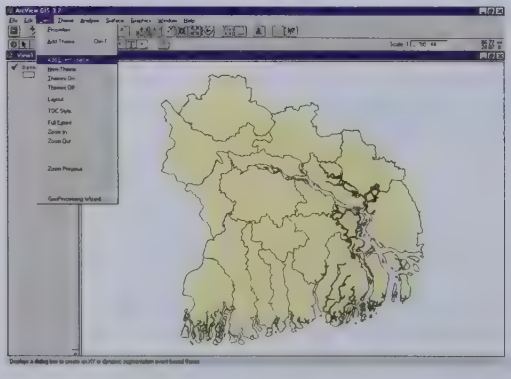
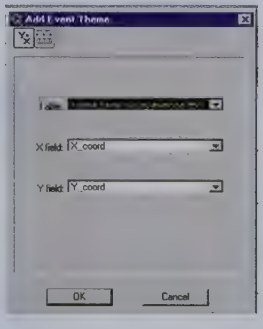


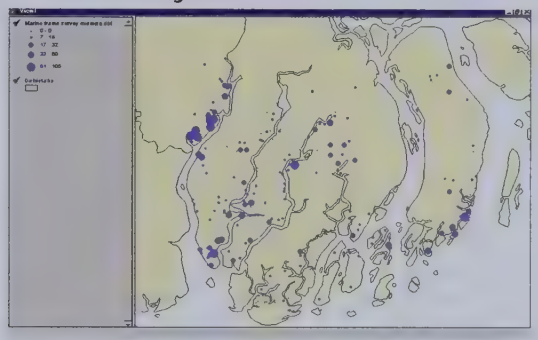
FIGURE 11.7
The Add Event Theme window



1. Once you are sure the correct file will be used, and the correct field will be used for the X and Y coordinates press **OK**. You will see a new **Theme** appear in the **View**, called 'Marine frame survey exercise.dbf'. Check the View Box and you will see that points appear in the southeast corner of Pais Pesca.

2. You can now analyse the data collected by the Department of Fisheries. Make a **View** showing the villages and the number of boats with graduated symbol in the Legend Editor (Figure 11.8).

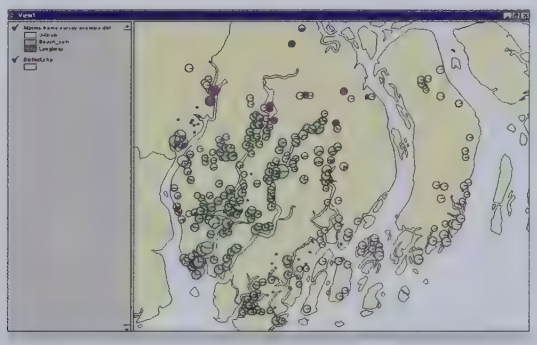
FIGURE 11.8
The villages with the number of boats



11.3 CALCULATION USING COLLECTED FIELD DATA

Also the distribution of the number of gear, and the type of gear is possible to show. Make this view (Figure 11.9).

FIGURE 11.9
The distribution of gear



This last exercise needed you to calculate the total number of gear, by adding a field and calculating the total number of gear. If you have forgotten how to do this, have a look at: Adding a field and making calculations in a table, on page 31.

11.4 GRAPHICAL DISPLAYS OF POINTS

In the previous chapters and exercises you have seen how to display data joined to a point Theme in the form of histograms or graduated colours and graduated symbols. The best plot is the **graduated symbol** as it gives in one view the distribution of the fishing boats along the coast and allows to identify quickly where the villages with large numbers of boats are.

The different forms of displaying data in GIS discussed until now are not appropriate if you want to know why there is a large number of boats, or large numbers of Tilapia in a certain area, or want to know if there is a gradient in the abundance of fish stocks and to which factors this gradient is related. For this you have to interpolate between the data at different locations, which is often done with a contour plot that connects data points with the same values.

12 Projection

12.1 MAP PROJECTION

Map projections are attempts to portray the surface of the earth or a portion of the earth on a flat surface. Some distortions of area, shape, distance and direction always result from this process. Some projections minimize distortions in some of these properties at the expense of maximising errors in others. Some projections are attempts to only moderately distort all of these properties.

Map projections can be generally classified according to the spatial attribute they preserve as shown in Table 12.1.

TABLE 12.1
Types of projections

Attribute preserved	Projection	Applications	Examples
Area	Equal Area	Many thematic maps use and equal area projection. Maps of the United States commonly use this projection.	- Albers Equal Area Conic
Shape	Conformal	Useful for navigational charts and weather maps. Shape is preserved for small areas, but the shape of a large area such as a continent will be significantly distorted.	- Lambert Conformal Conic - Mercator
Distance	Equidistant	No projection can preserve distances from all points to all other points. Instead distance can be held true from one point (or a few points) to all other points or along all meridians or parallels. If you will be using your map to find features that are within a certain distance of other features, you should use an equidistant map projection.	- Equidistant Conic
Direction	Azimuthal	Projections preserve direction from one point to all other points. This quality can be combined with equal area, conformal, and equidistant projections.	- Lambert Equal Area Azimuthal - Azimuthal Equidistant

Other projections minimize overall distortion but do not preserve any of the four spatial properties of area, shape, distance and direction. The Robinson projection for example, is neither an equal area nor conformal, but is aesthetically pleasing and useful for general mapping. ArcView supports a large set of standard projections with predefined projection parameters.

Map projections are designed for specific purposes. One map projection might be used for largescale data in a limited area while another is used for a smallscale map of the world.

12.2 CHANGING PROJECTIONS

Here are a few things to consider when choosing a map projection:

- What spatial properties do you want to preserve?
- Where is the area you are mapping? Is your data in a polar or an equatorial region?
- What shape is the area you are mapping? Is it square? Is it wider east–west direction?
- How big is the area you are mapping? On largescale maps, such as street maps distortions may be negligible because your map covers only a small part of the earth's surface. On small scale maps where a small distance on the map represents a considerable distance on the earth, distortion may have a bigger impact, especially if you use your map to compare or measure shape, area, or distance.

Answering these questions will determine what map projection and, thus, what projection coordinate system you will want to use to display your data. Your choice of projection will not be critical if your map covers a small area.

12.2.1 Different projections

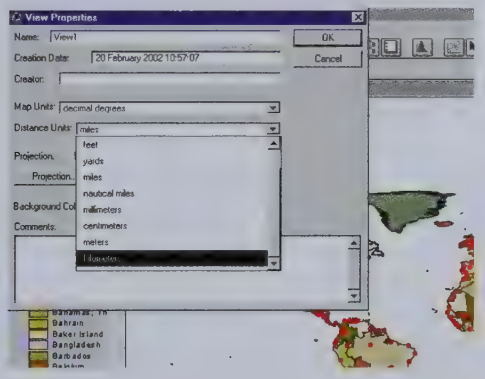
Map projection affecting distance

To demonstrate how projections can distort distance, you will measure the distance between two African cities (Tunis, Tunisia, and Cape Town, South Africa) using a map projection.

Geographic coordinate system

1. Open ArcView, Open a new project, and Open a new view.
2. Add the Themes 'worldmap.shp'[6] and 'world_cities.shp' from the '10_Projection' folder. Check the checkboxes of the Themes (so that the Themes become visible). If necessary, move the 'World_cities.shp' Theme above the 'Worldmap.shp' Theme.
3. Go to: **View/Properties...**via the menu bar, click **Projection** and you will see that the projection is 'Geographic'. Click **OK**, and select kilometres in 'Distance Units' (found at the bottom of the list) (Figure 12.1), click **OK**.

FIGURE 12.1
Distance units for the View projection



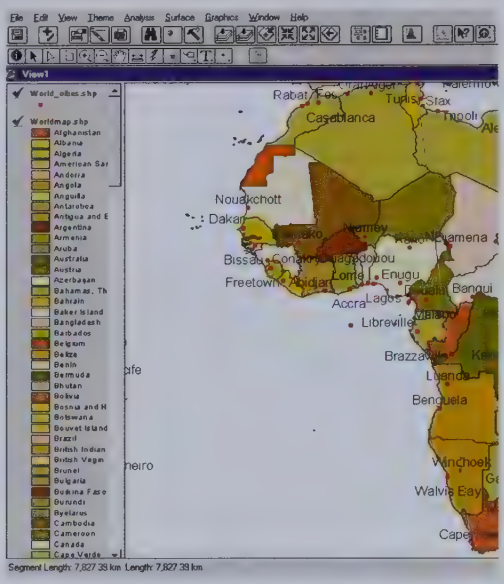
4. Click the zoom in button.
5. Click and drag a box around Africa.
6. Make the 'World_cities' Theme active, by clicking on it.
7. Via the menu bar, go to **Theme/Auto-label...**.
8. Leave the default settings as they are and click **OK**. If the legend fonts are too big you can reduce the font size in the **Legend Editor** (menu bar: **Theme/Edit Legend...**, double click on the symbol [here a blue dot], a palette screen pops up, select the font palette by clicking on the button with A, B, C, change the size, click apply, close all screens, remove the labels [**Theme/Remove Labels**], and autolabel again [**Theme/Auto-label**]).

The city labels are added to the display. Tunis is near the top of the display in Tunisia, and Cape Town is near the bottom in South Africa. If you cannot see both cities, zoom out or adjust the display so that they are both visible.

9. Click the measure button.
10. Click first Tunis then double-click Cape Town to measure the distance between the two cities. (Figure 12.2).

[6] 1994.

FIGURE 12.2
The distance between Tunis and Cape Town



The distance displays on the bottom left-hand side of the status bar. Your result should be around 8 000 kilometres (i.e. distance may be slightly different).

Now change the projection and measure distance again:

Behrmann equal area cylindrical

11. Select again **View** then **Properties** via the menu bar, click **Projection** and select 'Behrmann' in the **Type:** selection box, and click **OK**.
12. Remeasure the distance between Tunis and Cape Town.

The new distance should be around 8 500 km, a difference of 500 km!

Behrmann projection is suitable for world mapping. Shape distortion is minimized near the standard parallels. Shapes are distorted north–south between the standard parallels and distorted east–west above 30°N and below 30°S. Area is maintained and direction is generally distorted except along the equator.

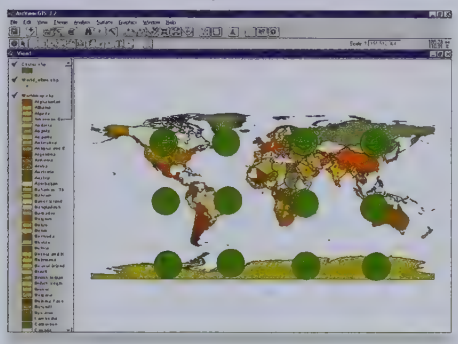
Map projection affecting shape

In this exercise you will clearly see (Figure 12.3) how shapes change when the projection changes. Circular shapes make it easy to see the distortions so we have included a layer with smiling faces that you will project along with the Worldmap shapefile.

Geographic coordinate system

13. Uncheck the 'World_cities' Theme to turn it off.
14. Click the Zoom to Full Extent button to view the complete View of the world, or go to **View/Full Extent** via the menu bar.
15. Select **View** then **Properties** in the menu bar, click **Projection** and select **Geographic** click **OK**.
16. Add the Theme 'Circles.shp' from the same folder ('10_Projection').
17. Check the 'Worldmap.shp' and 'Circles.shp' Themes (to make them visible).

FIGURE 12.3
The worldmap with circle faces



The geographic coordinate system is not a map projection so the circles are not distorted. Now change projections and examine the distortion of the circles.

Mercator

18. Select **View** then **Properties** in the menu bar, click **Projection** and select 'Mercator' then click **OK**.

Notice that small shapes are well represented. Area is increasingly distorted toward the Polar Regions. For example, Greenland is only one-eighth the size of South America but it appears to be much larger. The best use of this projection applies to regions near the equator such as Indonesia and the Pacific Ocean.

Try a couple of more projections to see how they distort the shapes of the faces. You can also try measuring distances to see if shape and distance are distorted in the same projection.

Map projection affecting area

Map projection changes by selecting the desired projection from the 'View' properties option above are useful for visualising spatial distortions for distance and shape. However, for 'area' estimates calculations need to be made as described below.

Geographic coordinate system

19. Select **View** then **Properties** in the menu bar, click **Projection** and select 'Geographic' click **OK**.
20. Check the 'Worldmap.shp' Theme to display the map, and click on the Theme legend to make it active.
21. On the Button bar click on the Open Theme Table button (or go via the menu bar to: **Theme/Table...**).
22. Select **Table/Start Editing** via the menu bar.
23. Select **Edit/Add Field....**
24. Name this new **Field** 'Area'.
25. Number of decimal places 2, click **OK**.
26. Click on Calculate button, or go via the menu bar to: **Field/Calculate....**
27. Select [shape] by double clicking on it.
28. Type '.returnarea' in the box at the bottom, so that the full taxt in the box looks like: '[shape].returnarea'.
29. Click **OK**. You will see the new field 'Area' filled with numbers.
30. Click on 'Cntry_name' and then click on Sort ascending button.
31. Look at the 'Cntry_name' column and then at the corresponding values in the new 'Area' column created. You will see that all these area values are all degree values. For example, look at Afghanistan, the corresponding values in degrees is 62.57.

In a geographic projection areas are calculated using map units, not distance units, so area values really reflect how many square 'degrees' there are. Degrees do not measure ground distance at all, but rather a fraction of a circle. Degrees of longitude/latitude are not consistent units of measure for area, shape, distance and direction.

- Stop editing by going to **Table/Stop Editing** in the menu bar. When you are asked if you want to 'Save Edits?' click **Yes**.
- Close the Table.

Now change the projection.

Equal-Area Cylindrical

32. Select in the menu bar **File** and then **Extensions...** and check 'Projector!'.

If you can not find 'Projector!' in the extensions list ('Projector!' is not the same as 'Projection Utility Wizard'), you have to do the following to get it in the extensions list: Open Windows Explorer, goto the folder where ArcView is installed (for instance C:\ESRI), Goto the the folder ESRI\AV_GIS30\ARCVIEW\. In this folder two subfolders are important for what we are about to do, namely \EXT32 and \Samples. The \Samples folder holds many extensions of which Projector! is one. Open the Samples folder and open its subfolder \ext (so the path will look something like: ...\ESRI\AV_GIS30\ARCVIEW\Samples\ext). Look in this folder for the file 'prjctr.avx'. Copy this file and paste it in the \EXT32 folder (the path looks something like:...\ESRI\AV_GIS30\ARCVIEW\EXT32). Now try again to find 'Projector!' in the extensions list, and check it (**File/Extensions...**).

33. Make sure you have 'Worldmap.shp' still active, and that the distance units are kilometres (**View/Properties...**)
34. Click on the 'Projector!' button.
35. Select 'kilometers'[7] from output units and then click **OK**.
36. In projection properties under 'Type' choose 'Equal-Area Cylindrical' projection then click **OK**.
37. You will get a popup with the question: 'Recalculate area, perimeter and length fields (if present) using kilometres? Click **Yes** to do this.
38. Then a pop-up will ask: 'Add projected shapefile(s) as theme(s) to a view? Again you click **Yes**.
39. In the **Projector!** window select <New View> and click **OK.** You will now be asked to save the file. Think of a proper name, and save the file on a location where you will be able to find it.
40. The new View will appear, check the new file/Theme for display and have a look (you even can change the display, so that you will see the same view as the one you have projected). Click the Theme, so that it is active.
41. On the Button bar click on the Open Theme table button, or via the menu bar: **Theme/Table....**
42. Click on 'Cntry_name' and then click on 'Sort ascending' button.
43. Now compare the 'Cntry_name' with 'Area' column, you will see that the degree values in area column are now the real surface area values. If you look at Afghanistan this time the surface area value is now 642 115.94 km^2.

When spatial data in your view is in decimal degrees, you can decide whether or not you want to choose a map projection. If your application doesn't require a high level of locational accuracy, if you will not be performing queries based on location, distance and area, or if you just want to make a quick map you do not need to choose a map projection.

Notes:

When data is projected, most of the time ArcView stores this projection information in the file with the same name as the Theme, with the extension '.prj'. This file can be read with for instance the notepad program of Microsoft.

Detailed information about each projection available in ArcView can be found in the on-line help. The help topic for each projection tells you what type of projection it is and how well it preserves area, shape, distance and direction.

By customizing a projection, you can tailor a projection's parameters to suit your needs. To learn more about the various projection parameters, use ArcView on-line help.

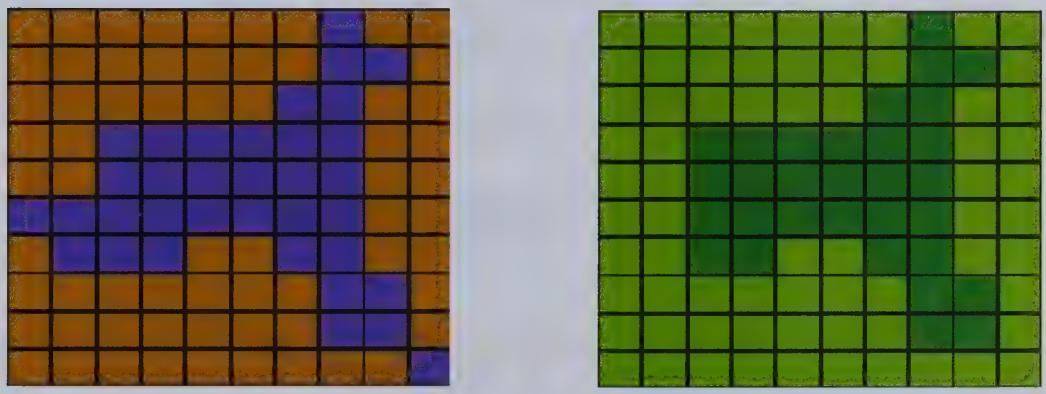
[7] The spelling for metres, kilometres, etc. will be metres, kilometres, etc. where the software is displaying the words as such.

13 Raster data

Raster data is a method for storage, processing, and display of spatial data. Each given area is divided into rows and columns, which form a regular grid structure. Each cell within this matrix contains an attribute (a characteristic of a geographic feature described by numbers or characters, typically stored in tabular format, and linked to the feature. For example, attributes of a well, represented by a point, might include depth, pump type, location and liters-per-minute).

A grid is commonly used to refer to a raster data model. A grid is a fully integrated grid (cell-based) geoprocessing system for use with ArcInfo (another ESRI GIS program). The term grid cell is often used to refer to a single element of a raster data structure. In other words: A grid layer consists of small squares (pixels or cells) of equal size with certain criteria attached to them (Figure 13.1).

FIGURE 13.1
Grid files with pixels



In the left grid, blue pixels represent water and brown pixels represent dry area. In the right grid light green represents a rice species with a short stem, while the dark green represents a longstem rice species. From this very rough picture, you could conclude that a long stem rice species needs to be flooded, while the short stem species needs its 'feet' to be dry. Of course it is possible to draw lots of other conclusions, making it clear that a crude picture alone is not enough to draw substantial conclusions.

The level of detail, or level of accuracy of a grid layer depends on the size of the raster cells also called resolution. Smaller pixel sizes also means increased number of pixels and increased size of the files. Raster files of 1–2 megabytes are quite common in a GIS analysis and a fairly simple GIS analysis easily requires about 200–300 megabytes of free hard disk space to store all the generated raster files.

Raster data can be derived from:

- Satellite images.
- Scanned images.
- Conversion of vector data to raster data, for instance the crop grid file presented previously was made by putting the areas with crops from a satellite image on a digital map (digitising) after which the created polygon shapefile of the different crops was converted into a raster data, or grid file.
- Spatial interpolations. The previously presented water level grid file was generated from water levels measured at a number of points in the area. A point shapefile

of the water reading stations was made. The data on water levels were joined and a grid was generated through a surface plot which is in principle a contour plot only that the data are presented with pixels instead of with contour lines.

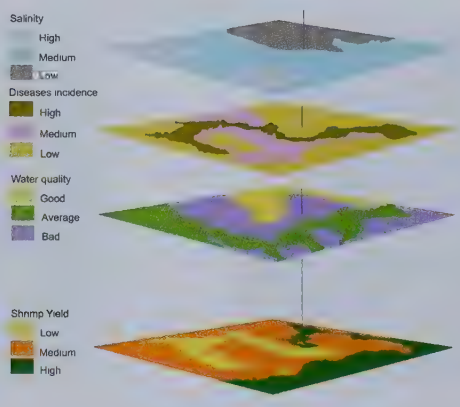
13.1 OVERLAY

Data from different locations (points) can be interpolated to generate raster data files, surface plots. We all know examples of these from the pre-GIS period, like contour lines made from topographic maps, salinity lines in the coastal areas.

GIS has a number of powerful mathematical tools to create these raster data files. Once a number of these files (of different parameters for the same area) are made, interactions or relations between the different layers, or data sets can be explored with GIS.

For example, GIS could be used to analyse whether in a certain area there is a relation between the occurrence of White Spot disease in shrimp farming and parameters such as water quality in the ponds or major canals, salinity level, feeding levels, stocking density of post larvae, etc. Figure 13.2 gives a graphical representation of this concept, which is also known as the overlaying principle. This principle is the basis of many raster analyses.

FIGURE 13.2
Example of different grid layers



It can not be stated enough that GIS is much more than a sophisticated tool to make nice maps for reports. It is a tool for spatial analysis of data.

To work with raster data in the ArcView program you need the Spatial Analyst extension. Extension are plug-ins that you can load and unload as you need them. The ArcView Spatial Analyst is an extension for ArcView 3.x. This extension allows you to create, query, map, and analyse cell-based raster data and to perform integrated vector analysis.

13.2 HOW TO SET YOUR DEFAULTS FOR THE USE OF SPATIAL ANALYST AND CHANGE THE WORKING DIRECTORY

13.2.1 Settings of Spatial Analyst

The Spatial Analyst extension needs to be purchased, as it does not come with the ArcView Package. To work with this extension you first have to install Spatial Analyst and then activate it in the ArcView program. After you have started ArcView, go to **File/Extensions...** via the menu bar (Figure 13.3), which opens the **Extensions** window, check the Spatial Analyst box, then check the box 'make default' and select **OK** (Figure 13.4).

FIGURE 13.3
Opening the ArcView Extensions window

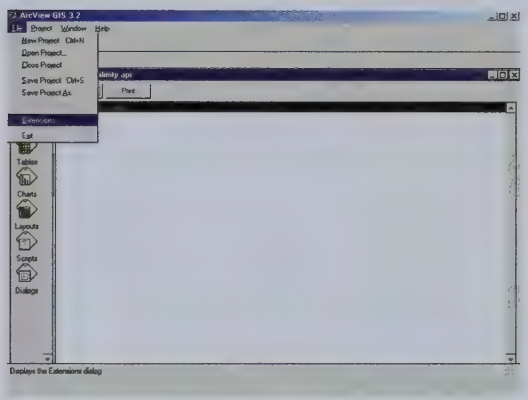
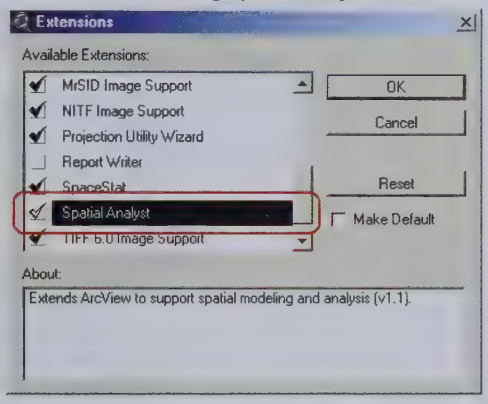


FIGURE 13.4
Activating Spatial analyst



13.2.2 Changing the working directory

If you create new files in ArcView in most cases they will be automatically saved in the working directory 'C:\windows\temp'. In the next chapters we will start to work with grids and learn how to make grids. If you keep the defaults of ArcView these files will be all saved in 'C:\windows\temp'. However other, non-ArcView files, will also be saved in this directory. Therefore it is recommended to store all the new data in a separate folder, like for instance 'C:\FAO_FISH_GIS\Temp\', but you can also think of another more appropriate folder name for you of course. If you start a new project you have to set the working directory to this directory of your choice by:

1. In **View** go to **File/Set Working Directory** via the menu bar (Figure 13.5).
2. The working directory window will popup and you need to change the name of the working directory to 'C:\FAO_FISH_GIS\temp' or any other diretory of your choice (Figure 13.6) and click **OK.** Whenever the directory C:\FAO_FISH_GIS\temp is mentioned, you can also read the folder name you have designated for temporary files.

FIGURE 13.5
Setting the working directory

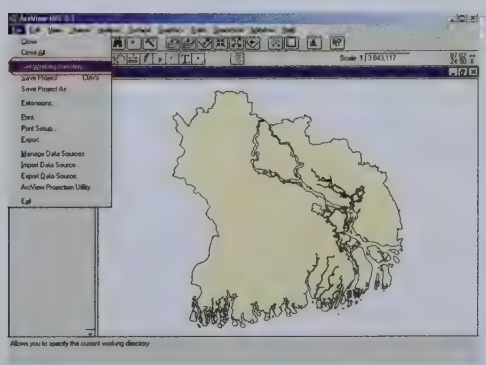


FIGURE 13.6
Changing the working directory name

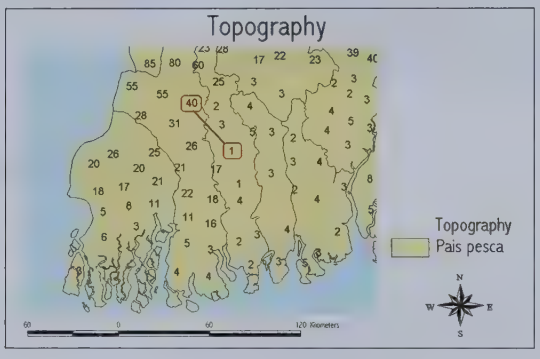
13.3 MAKING SURFACE PLOTS

Surface plots have many applications in fisheries, therefore more detailed information on how to make surface plots/grids is given in this chapter. The basic characteristics of a surface plot or grid are similar to those of contour lines; it connects data points with similar values. The large difference of a grid, if compared with contour lines, is that the areas in between two points also have a value added to their pixels, by an interpolation.

13.4 HOW THE INTERPOLATION OF THE DATA WORKS

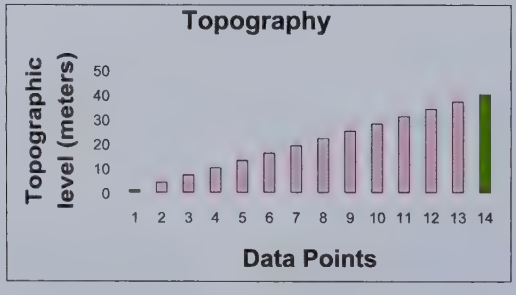
In Figure 13.7, topographic levels in the coastal area of Pais Pesca are presented with two values highlighted; one low value of 1 metre in the south and one of 40 metres in the north.

FIGURE 13.7
Two topo levels in the coastal area of Pais Pesca



In Figure 13.8 the theoretical topographic levels of 12 points between the two extreme points (the extremes in green, data point 1 and 14) are calculated. It is assumed that the topographic gradient is linear in relation to the distances between the two points. The exact way ArcView interpolates is more complex as it interpolates between all data points or a selected number of data points simultaneously so that you get a kind of web of calculation. For more details on the interpolations, see the notes below.

FIGURE 13.8
Theoretical example of Interpolation



Note 1: Surface interpolators

The surface interpolators in ArcView make certain assumptions about how to determine the best estimated values. The values represent how the sample points are distributed. No matter which interpolator is selected, the more input points and the greater their distribution, the more reliable the results.

The **Inverse Distance Weighted** (IDW) interpolator assumes that each input point has a local influence that diminishes with distance. It weights the points closer to the processing cell greater than it does those further away. A specified number of points, or optionally all points within a specified radius, can be used to determine the output value for each location.

The **Spline interpolator** is a general-purpose interpolation method that fits a minimum-curvature surface through the input points. Conceptually, it is like bending a sheet of rubber to pass through the points, while minimising the total curvature of the surface. It fits a mathematical function to a specified number of nearest input points, while passing through the sample points. This method is best for gently varying surfaces such as *elevation, water table heights, or pollution concentrations*. It is not appropriate if there are large changes in the surface within a short horizontal distance, because it can overshoot estimated values, and no barriers can be set.

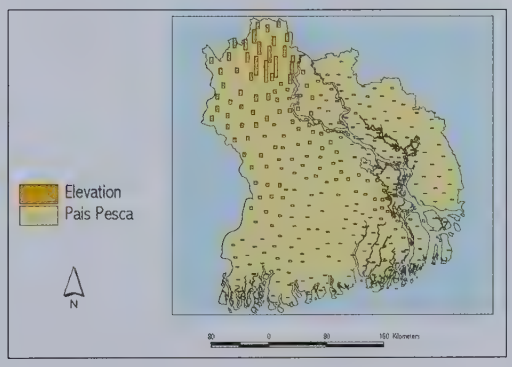
Note 2: Kriging

Kriging is an interpolation method available in Spatial Analyst, however you need to be able to do a bit of Avenue programming to be able to apply this. Readily available Kriging tools can be downloaded from the internet (at for instance: http://gis.esri.com/arcscripts/index.cfm, or http://www.absc.usgs.gov/glba/gistools for Spatial Tools [Spatial Tools is an ArcView extension that contains a collection of 32 tools that extend the capabilities of Spatial Analyst]). Kriging is based on the regionalized variable theory, which includes drift, random correlated components and noise. Kriging produces a statistical optimal surface grid and indicates with a variogramme where your plots are getting into problems. More information on Kriging is provided in Annex C: Kriging on page 155.

13.4.1 The topographic map of Pais Pesca

The best way to explain how to make a surface plot is to carry out an example, and for this we use the elevation levels of Pais Pesca. In 1999 the Department of Geography of Pais Pesca carried out a topographic survey all over the country. The data collected are presented in Figure 13.9.

FIGURE 13.9
Histograms of elevation of Pais Pesca



You will see immediately that the elevation levels in the northwest are highest, as the area is hilly. The elevation decreases in the south, as here are the coastal plains. Make a topographic map of Pais Pesca by interpolating the values lying in between the data points in Figure 13.9. This is done by making a surface plot with Spatial Analyst.

1. Start ArcView.
2. Start new Project.
3. Make sure that Spatial Analyst is set to default in the **Extensions** window (menu bar: **File/Extensions...**).
4. Open a new View.
5. Set the projection of the view to Projections of the world/Equal area cylindrical and set the distance units in meters.
6. Set the working directory to your directory of choice, for instance: 'C:\FAO_FISH_GIS\temp'. (menu bar: **File/Set Working Directory...**).
7. Add the **Theme** 'Pais_pesca country.shp' from the folder \11_PPTopo from the CD.
8. Add the **Theme** 'Pais pesca elevation.shp'. This is a point shapefile with elevation values as measured by the Department of Geography.
9. Activate the 'Pais Pesca elevation' **Theme.**
10. Go to **Surface/Interpolate Grid...** via the menu bar (Figure 13.10).
11. The **Output Grid Specification** window will pop up (Figure 13.11). In this menu the characteristics of the newly created grid are specified. Select 'Same as

FIGURE 13.10
Start surface interpolation

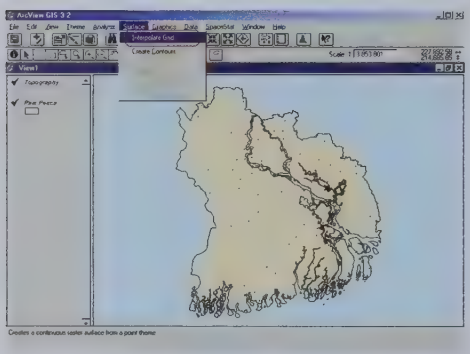
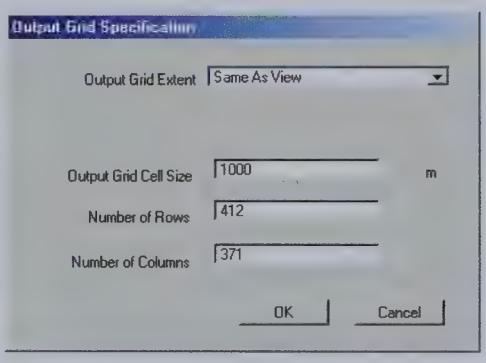


FIGURE 13.11
The Output Grid Specification window



View' in the **Output Grid Extent** box, which means that the new grid will cover the whole **View**, including the areas not visible on the screen. If you select 'Same As Display' the grid will only be made for the area we see at that moment on the screen.

12. Enter as output grid cell size 1 000 metres. Each created pixel will have a size of 1 000 x 1 000 metres or 1 square kilometre. The number of rows and columns will automatically adjust according to the specification of this cell size, after you press the enter key on your keyboard. Click **OK.** Attention!: You need to realize that the lower the Output Grid Cell Size is, the higher the number of cells to be calculated is. Later on in this chapter you will have to make interpolations, calculations, and queries with cell sizes of 100 metres (giving a cell area of 10 000 m^2, or 1 hectare). If you do this for the whole of the 'Pais pesca country.shp' Theme, your PC has to calculate approximately 3 800 cells times 4 000 cells (depending on the projection) meaning 15 200 000 cells! While now with the cell size 1 000 metres (meaning a cell area of 1 000 000 m^2, or 1 km^2) the PC only calculates 412 cells times 371 cells, 152 852 almost thousand times faster!
13. The **Interpolate Surface** window will pop up (Figure 13.12). In the method we can choose between 'Inverse Distance Weighted' (IDW) and the 'Spline Interpolator' In this case we select 'IDW' as we have irregular variation in the hilly area in the northern part of the country.

14. As **Z-value,** the value to be interpolated, we select 'Elevation'. The other settings i.e. **Number of Neighbours, Power** and **Barriers** we do not change[8].

FIGURE 13.12
Progress of surface interpolation

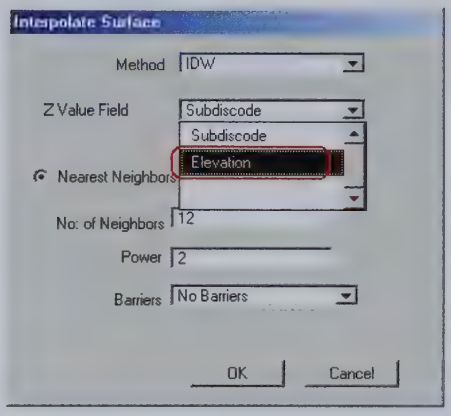
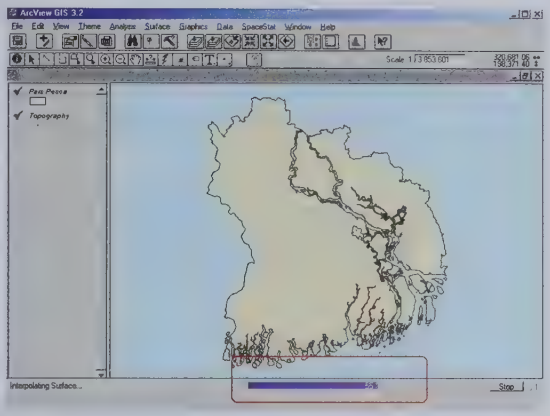


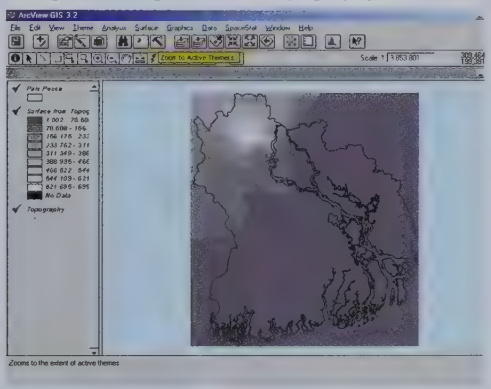
FIGURE 13.13
Interpolate Surface window



15. Click **OK,** the interpolation starts, and a blue bar in the right bottom corner indicates the progress of the interpolation (Figure 13.13).

After some time the interpolation is complete and the created grid file will be added automatically to the **View.** Move the Pais_Pesca_Country.shp theme above the surface plot theme. (Figure 13.14).

FIGURE 13.14
The generated grid for the topography of Pais Pesca



Note:

When you create new grid files, they are automatically stored in the default temporary directory, often 'C:\windows\temp' or 'C:\temp'. If you carry out a number of different analyses, they are all stored there and are later difficult to separate. Therefore it is strongly recommended to make for each analysis a separate directory, e.g. if you work with a shrimp theme you could make a temporary directory 'C:\temp\shrimp\' and set the working directory for each project you carry out for the shrimp analysis to this temporary directory. Set the working directory in a project by going from the view of a project via the menu bar to **File/Set Working Directory**.

For all our exercises we need to set the working directory to a directory of your choice, for instance C:\FAO_FISH_GIS\temp.

[8] Please read the more specialized reference books for information on these settings and when to change them.

In the example you created a new Grid called 'Surface from topography' this is stored as 'C:\FAO_FISH_GIS\temp\sface1' (if you used the working directory C:\FAO_FISH_GIS\temp\). The next interpolation you make will be saved as 'C:\FAO_FISH_GIS\temp\sface2'. As you understand, the numbering is done automatically by ArcView. If you make a number of interpolations and you want to use one of them later in another project, you will have difficulties finding it again. You can, however, save the newly created surface grid under a name of your own choice just after you have made it by going to **Theme/Save Data Set...** via the menu bar. If you forget this, it is not easy to change the names later.

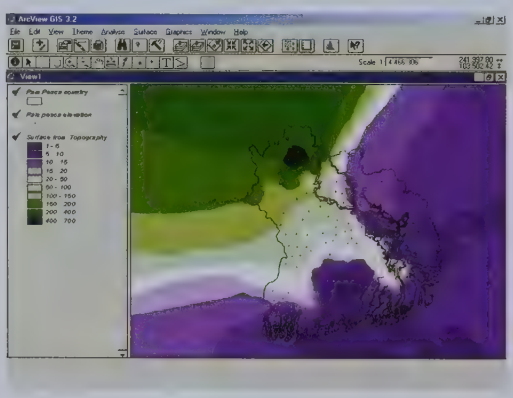
Naming convention:

The maximum number of characters of a name in ArcView is 13. No spaces or periods are allowed, and you must not put an extension. ArcView will not recognize grids located in paths containing periods (".") or spaces (" "). This applies to all new grids made by **Map calculation, Surface interpolation, Queries** and **Reclassification**.

In the following exercises you will see how to convert a shapefile to a grid file. The new created grid is automatically saved as 'C:\FAO_FISH_GIS\temp\nwgrd1'; the second one as 'C:\FAO_FISH_GIS\temp\nwgrd2', etc. You can give the grid a name of your own choice by changing the name, 'nwgrd1', in the window once it appears. Again, changing the name later and finding your files is difficult.

The topographic level of Pais Pesca varies from 1 to about 700 metres. After the generation of the surface grid ArcView automatically divides the grid level in equal intervals. In our case it means that small differences in the topography in the plains and coastal area are not visible. Appropriate legend and classification is something you have to do yourself. If you do not remember how to do that, have a look at page 15, Changing the number of classes in a legend. Our selection is presented in Figure 13.15.

FIGURE 13.15
Topography Pais Pesca

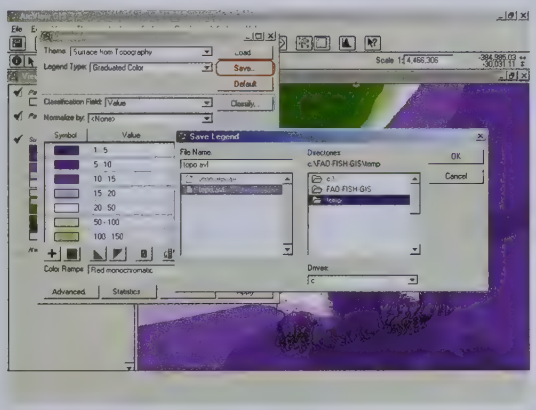


Tip: Saving and Loading a legend style

Creating a legend is usually time consuming. Hence, once you have created a legend it is recommended to save these legends so that it can be later used for the same grid or with a newly generated grid (Figure 13.16) by opening it in the legend menu. To save a legend of the active Theme, open the **Legend Editor** (either by double-clicking the Theme, or by going to: **Theme/Edit Legend...**), click on **Save**. The **Save Legend** window will pop-up. Give the legend style an appropriate name, and navigate to an appropriate folder where you want to save the file containing the legend style. Once you have done that, click **OK**. The file will now be saved with the name you have given it, and the extension'.avl'.

Loading a legend style you have made before is easy: activate the Theme which you want to use the saved Legend for, open the **Legend Editor** (either by double-clicking the Theme, or by going to: **Theme/Edit Legend...**). Click on **Load**, and navigate to the correct file in the correct folder (remember that the file needed will have the extension '.avl'. Select the file, and click **OK**.

FIGURE 13.16
Saving a legend style



The generated topography grid from Pais Pesca looks fine. However, we see immediately something strange; the interpolation is carried out over the borders of Pais Pesca. To solve this situation the generated grid can be improved by setting a **mask** before carrying out the surface interpolation.

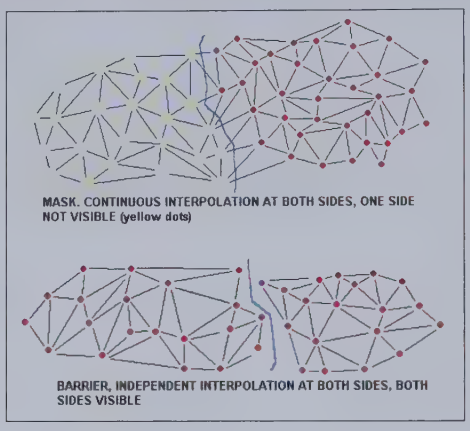
13.5 HOW TO SET A MASK IN A GIS ANALYSIS

We will carry out the same exercise as before, but now with the Pais Pesca borders giving the boundaries of the analysis. First we have to know how to set the boundaries for a GIS analysis.

There are two ways to set the boundaries for an interpolation or analysis, and the way they work are fundamentally different.

- Making a boundary by setting a **Mask;** in principle, a mask delimits the area you will see after you have made the calculation or interpolation. The calculations are carried out beyond the boundaries of the mask. By putting a mask in our example, we still create topographic levels in the neighbouring countries of Pais Pesca with data of Pais Pesca, only we do not see them and they are not stored. Setting a mask is the easiest way to define a boundary for an analysis and provides reliable results.
- Another way is to define the area where the interpolation takes place with **Barriers**. When you set a barrier, the calculation/interpolation will not be carried out beyond it. In our example, it means that an interpolation is only carried out within the boundary of Pais Pesca. Barriers are more difficult to apply as they work with line shapefiles only and are not further discussed in this manual.

FIGURE 13.17
The difference between a mask and a barrier during interpolation in ArcView


MASK. CONTINUOUS INTERPOLATION AT BOTH SIDES, ONE SIDE NOT VISIBLE (yellow dots)
BARRIER, INDEPENDENT INTERPOLATION AT BOTH SIDES, BOTH SIDES VISIBLE

Masks can only be set with grid files. The next example shows how to convert a shapefile into a grid file.

13.5.1 Pais Pesca: Topography with mask set

Making the mask

1. Start ArcView.
2. Start a new project.
3. Open a new View. Set the projection of the view to Projections of the world/Equal Area Cylindrical and set the distance units in meters.
4. Set the working directory to 'C:\FAO_FISH_GIS\temp', or another directory of your choice.
5. Add the 'Pais_pesca_country.shp' Theme from the '11_PPTopo' folder.
6. First we will make a mask by converting this polygon shapefile to a grid file. Activate the Pais_pesca_country shapefile. Go to **Theme/Convert to Grid...** via the menu bar (Figure 13.18).

FIGURE 13.18
Going to Theme/Convert to Grid

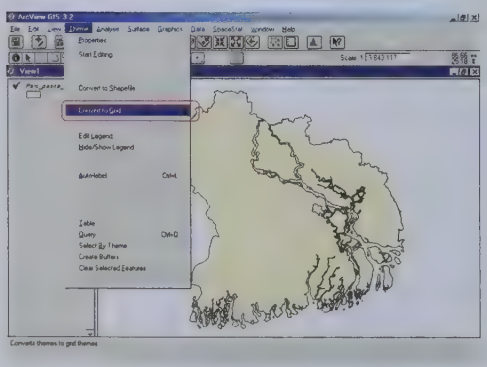
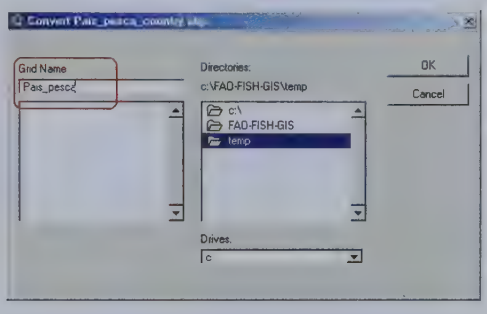


FIGURE 13.19
The Convert to gridname window



7. The Convert to gridname window will popup (Figure 13.19). If you have set the working directory correctly the new grid will be saved as 'nwgrd1' in the subdirectory 'C:\FAO_FISH_GIS\temp[9]. Change this name in the Grid Name box to Pais_pesca[10] and click **OK**.
8. The **Conversion Extent** window will popup. As **Output Grid Extent** we keep 'Same As Display' in the **Output Grid Cell Size** box we fill in 1 000 (Figure 13.20) This will again gives us pixels with a real size of 1 square kilometre. If meters are not indicated after the cell size box it means that you forgot to set the proper projection or distance units in the View Properties window. Click **OK.**
9. The **Conversion Field** window will popup, select 'ID' as **Field** (Figure 13.21) and click **OK**.
10. The conversion will start and you will be asked: 'Join feature attributes to grid?' and 'Add grid as theme to the view?' in both cases you click **Yes** and the generated grid will appear in the View. Zoom in at the borders and you will see the pixels (Figure 13.22). You can increase the resolution by decreasing the pixel size to 100 metres[11] but this will increase file size from 90 000 bytes to 500 000 bytes and therefore will take almost ten times more time to be ready.

Interpolation with the Pais Pesca grid set as mask

FIGURE 13.20
Setting the output extent

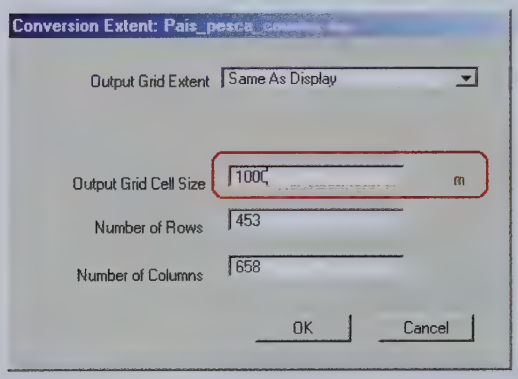


FIGURE 13.21
Selecting the field used in the grid conversion

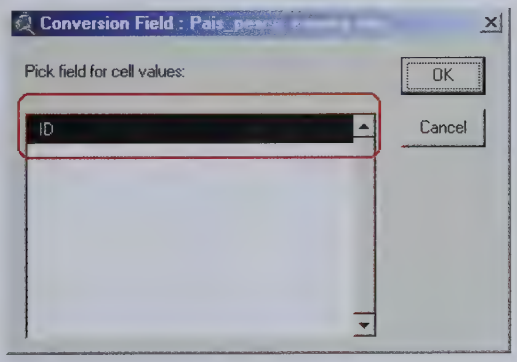
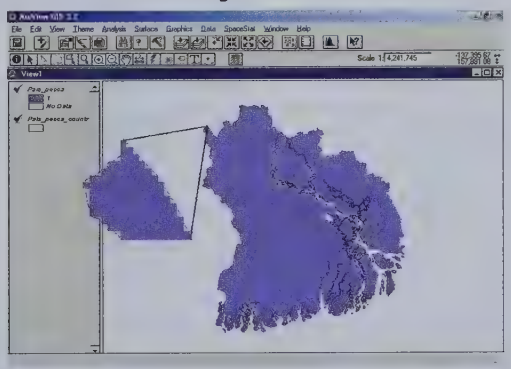


FIGURE 13.22
The created grid file of Pais Pesca

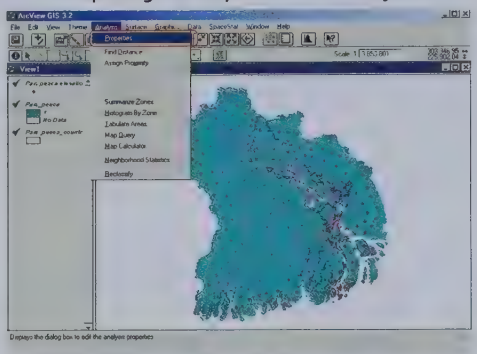


The interpolation is carried out as described before (on page 48), first we set the mask[12].

[9] If you do not see C:\FAO_FISH_GIS*.* (or another directory of your choice), you forgot to set the working directory. Start again after you have set it.
[10] Do not forget the naming convention! Just try to type 'Pais pesca' and see what happens.
[11] Try this out yourself.
[12] In ArcView 3.0 the mask is set in the interpolation menu.

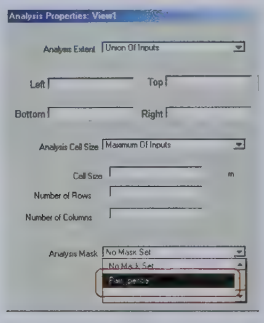
1. Go to **Analysis/Properties** via the menu bar (Figure 13.23).

FIGURE 13.23
Opening the Properties of an analysis



2. The **Analysis Properties** window will popup. Here we only[13] fill in the last window **Analysis Mask** (Figure 13.24) where we select 'Pais Pesca' the grid we just made before, Click **OK.**

FIGURE 13.24
Selecting the mask for an analysis

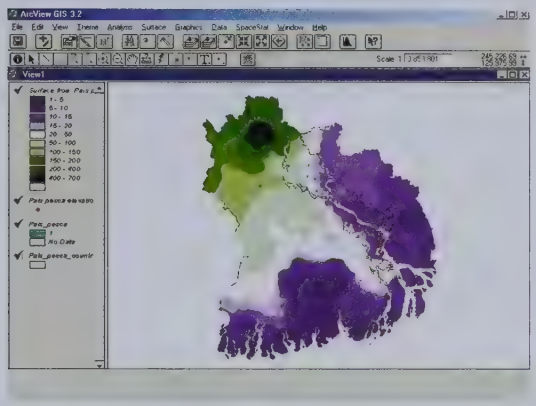


The mask is set and we carry out the analyses exactly as before.

3. Check if the working directory is set properly.
4. Add the 'Pais Pesca elevation' **Theme,** and activate it. Activating a Theme means that the legend of this Theme looks elevated (higher than the rest). It does not matter whether or not the check box is checked.
5. Go to **Surface/Interpolate Grid** via the menu bar.
6. The **Output Grid Specification** window will pop up. Select 'Same as View' in the **Output Grid Extent** box. Enter **Output Grid Cell Size** again as 1 000 meters, click **OK.**
7. The **Interpolate Surface** window will pop up. Select 'IDW' as topographic levels can change quickly, especially in the hilly areas. As **Z-value** we select 'Elevation', click **OK.**
8. The interpolation will start and the created grid will be added to the view.
9. Manipulate the legend and the colours and you will find the grid as presented in Figure 13.25. Do not forget to make the no data legend without colour.
10. Click with **Identify** on the grid outside the borders of Pais Pesca. What do you see?
11. Do not forget to save your surface grid now under a different name (menu bar: **Theme/Save Data Set...**). Once you have saved a grid with the name you choose, add that grid to your View and delete the original Theme, so that there will not be any confusion later on (see also page 52).

[13] The rest of the options are not discussed in this manual. Please refer to the handbooks.

FIGURE 13.25
Topographic map of Pais Pesca created with a mask set



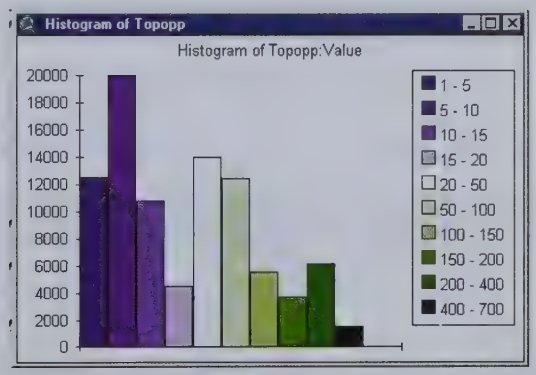
Note:

Once the mask is set it will remain attached to this view. With all other analysis carried out in this view this mask will be considered. If you do not want a mask in another analysis, you will have to remove it. Check always before you carry out an analysis the **Analyses Properties** otherwise you can get unexpected results. Imagine what will happen if you have set your mask for the coastal districts and afterwards you want to carry out an analysis for the whole country.

13.5.2 Histogram of created grid files

To get a quick look at the characteristics and distribution of a grid we can use the **Histogram** function. Activate the newly create grid, click on the **Histogram** Icon, the histogram of the distribution of pixels over the different classes will appear. On the X-axis you will find the different classes of elevation, while the Y-axis shows the number of pixels (Figure 13.26).

FIGURE 13.26
Distribution of land with different elevation in Pais Pesca



In our case the area of each pixel is one square kilometre as we selected 1 000 metres as output pixel size. It can be deducted from the histogram that the elevation class 5–10 metres has the largest area, 20 000 km². Fill in the following table (Table 13.1):

TABLE 13.1
Areas of different elevations

Land elevation	Area (Km^2)
1-5	
5-10	20 000
10-15	
15-20	
20-50	
50-100	
100-150	
150-200	
200-400	
400-700	

13.5.3 Pais Pesca salinity grid and water depth grid

Open a new **Project**, and a new **View**. In the **View**, Add the **Themes** from the '11A_Salinity_Grid' folder: 'pais_pesca_country.shp', 'salinity.shp', 'Pais pesca coastal depths.shp', 'Pais pesca sea boundary.shp', and 'pais pesca salinity boundary.shp'.

1. Check the working directory (for instance: 'C:\FAO_FISH_GIS\temp').
2. Set the **Projection** of the **View** to Projections of the world/ Equal-Area cylindrical and set the distance units in meters.
3. Convert the two Themes 'pais pesca salinity boundary.shp' and'Pais pesca sea boundary.shp' to a grid (via menu bar: **Theme/Convert to Grid...**) with a grid size of 100 metres, give them an appropriate name[14].
4. Make a salinity grid by interpolating the Theme 'salinity.shp' (menu bar: **Surface/Interpolate Grid...**), with 100 metres output grid cell size and the Salinity boundary grid set as mask (Figure 13.27). Be patient with the interpolation, this might take a long time. If it takes too long for you, try a grid cell size of 1 000 metres. Of course, the area of a pixel will change then aswell.
5. Make a histogram of the grid. What is the real area of 1 pixel[15]?
6. Make a coastal depth grid, with 1 000 metres grid size and the Sea boundary grid set as a mask (Figure 13.28).
7. Make a histogram of the grid, what is the area of 1 pixel?

FIGURE 13.27
Salinity levels in the coastal areas of Pais Pesca

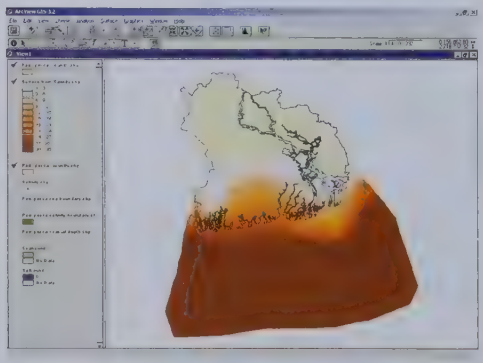
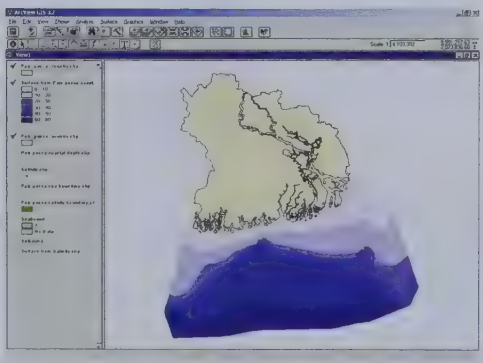


FIGURE 13.28
Depth of the Bodor sea



[14] Do not forget the naming convention.
[15] As the pixel is 100 metres * 100 metres, the area is 10 000 m^2, which equals to 1 hectare.

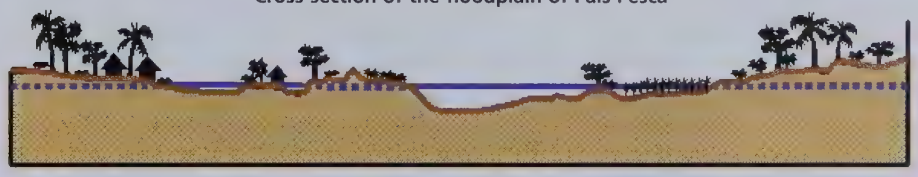
14 Calculation with grids using GIS

14.1 MAP CALCULATIONS

In a grid, each pixel has a characteristic attached to it. This can be a code but also a number, as for example water level or topographic level. Once grids are compared in the same location, it becomes straightforward that you can make calculations between grids.

Let us look at an example. In Figure 14.1 a cross-section is presented from the floodplains in Pais Pesca with the brown line representing the topography of the land and the blue line the water level.

FIGURE 14.1
Cross-section of the floodplain of Pais Pesca



In the cross-section, the blue line is a surface plot generated for water levels (like the one you made before) and you see immediately that there is water in places where the topo-level (brown line) is lower than the surface plot. To make a flood map, i.e. the real extent of flooding, you need the generated water level grid and a grid representing the topography of the floodplains.

Both grid files have values attached to each pixel. This allows us to calculate the water depth at each location presented by a pixel by simply subtracting the value of the topo-level from the water level.

Water depth = Water level-Topo level

An example of this calculation is presented in Table 14.1, and it is clear that once the value of the water depth becomes negative the area is dry.

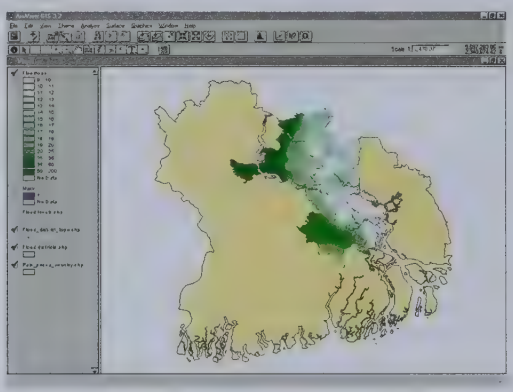
TABLE 14.1
Example of calculation of water depth in the floodplain of Pais Pesca

Water Level *(cm above sealevel)*	Topo level *(cm above sealevel)*	Water level-Topo level *(cm)*	
1 280	1 300	-20	Dry
1 310	1 280	30	Flooded
1 310	1 210	100	Flooded
1 310	1 100	210	Flooded
1 360	1 100	260	Flooded
1 380	1 223	157	Flooded
1 300	1 250	50	Flooded
1 290	1 300	-10	Dry
1 290	1 300	-10	Dry
1 280	1 350	-70	Dry

The same procedure, but now in ArcView:

1. Start ArcView, open a New Project, and a New View. Add the Themes 'Pais_Pesca_country.shp', 'Flood_districts.shp', 'Flood_district_topo.shp', and 'Flood_levels.shp' from the '12_Calc_with_grids' folder. Project the view (via the menu bar: **View/Properties.../Projection...**, 'Equal area cylindrical'), and set the distance units to meters.
2. Make first a topographic map of the floodplain districts involved: First you want to make a grid of the 'Flood districts.shp' Theme (**Theme/Convert to Grid...**, Grid name: 'Mask', Output Grid extend Same as View, Cellsize 100 meters), set this grid as a mask in the analysis properties, and only after that interpolate the topolevels.
3. Make the 'Flood_district_topo.shp' Theme active, go via the menu bar to **Surface/Interpolate Grid...** (output grid extend: Same as View, Cell size 100 meters, Method: IDW, Z-value field: what do you think?[16]). This interpolation may take a long time. Save the grid as 'Floodtopo' in a folder you choose. After the interpolation, you can load the legend that was made for this grid ('Topo.avl'). If you do not remember how to load a legend, please have a look at the tip on page 53.

FIGURE 14.2
The topographic level of the districts involved



If the interpolation takes too long, you can stop the process and load the interpolated grid. (From the folder '12_Calc_with_grids', Data Source Type: Grid Data Source, 'floodtopo'. If you can not add the grid to your View, and you are sure the grid is in a certain subfolder, check if the path to this subfolder follows the naming convention of ArcView (see the remarks on the naming convention on page 52, it might be that somewhere in the path to your file there is a space, or a name that is longer than 13 characters. After you added the grid, load the legend [in the legend editor]: 'topo.avl'). The results of your efforts should look like Figure 14.2.

The previous interpolation took such a long time, because ArcView had to calculate the waterlevel for every cell in the view (3767 cells by 3 983 cells, resulting in a total of 15 003 961 cells!). The calculation time can be reduced, when you reduce the number of cells that need to be calculated. You can do this by increasing the cell size. If you increase the cell size from 100 to 1 000, the number of cells decreases to (377 * 398) = 150 046 cells. By doing so, the grid you create will have quite a low resolution, with

[16] Topolevel of course.

which it is difficult to do meaningful analysis. Another way to reduce the number of cells to be calculated, and keep the same resolution (CellSize: 100), is to zoom in on the area where you want the calculation to take place, and make the Output Grid Extent 'Same As Display'. If you do this, you have to pay special attention that you include the whole area you want the calculation with, otherwise your calculation is worthless, and you have to do it again.

Now you need to make a grid with the water levels during October. Have a look at the table of attributes of the Theme 'Flood_levels.shp'. You will see that there are two water levels per record, October and June water level, for now you will make the grid with the October water level.

4. Make sure you still have the mask set (in the menu bar: **Analysis/Properties...**) (this should be 'Mask', the grid you made previously at 3. of 'flood_district_topo.shp'). Activate the 'Flood_levels.shp' Theme. Go via the menu bar to **Surface/Interpolate Grid...** (Output Grid Extend: Same as View [if the previous interpolation took a long time you can reduce that this time by zooming in on 'Flood_levels.shp' and making the Output Grid Extend: Same As Display], Cell size 100 meters, Method: IDW, Z-value field: what do you think?[17]). Also this might take a long time, and also for this interpolation the result is already in the folder if you can not wait for the interpolation to take place ('Watersurf', legend: 'Water_levels.avl').

If you have interpolated the grid yourself, you can save this grid as 'Watersurf' (menu bar: **Theme/Save Data Set...**) in a folder you choose, and change the name of this Theme into Watersurf (Theme/Properties...). Only if you change the name of the Theme (via the menu bar: **Theme/Properties...**, Theme Name:) will the this name appear in the Table of content (on the left side of the View).

Why do you not see a water level in the river and big lake in the centre of the flood districts?[18]

Now you have the two grids 'Watersurf' and 'Floodtopo' of the same area in your View, both with the same grid dimensions of 100 meters. Calculate the water depth in the floodplain with the formula: **Water depth = Water level – Topo level.**

1. Go to **Analysis/Map Calculator...** via the menu bar (Figure 14.3). The **Map Calculation** window opens (Figure 14.4).

FIGURE 14.3
Opening the map calculation menu

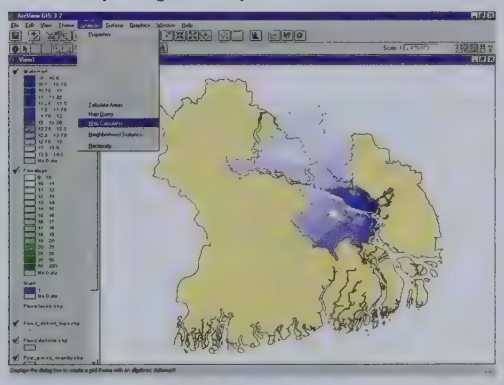
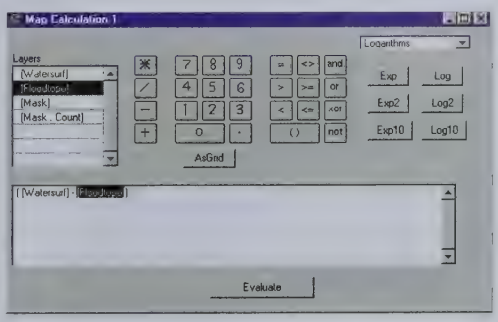


FIGURE 14.4
Calculating the water depth in the floodplain



[17] The floodlevels of October, in the column Oct.

[18] Because they are outside the mask you have set before the analysis!

2. In the window you see the names of the grids; [Watersurf], [Floodtopo], [Mask] and [Mask.count]. The calculation you need to carry out will be with the first two. Simply enter the formula by double-clicking [Watersurf], then '-', followed by double-clicking [Floodtopo]. Click on **Evaluate** to start the calculation, and close the **Map Calculation** window after the results appear as the Theme 'Map calculation 1'. Save this Theme[19] as 'Fldepth', before you change anything else!!! (**Theme/Save Data Set...**).
3. Redo the legend of 'Fldepth' in such a way that water becomes various gradients of blue and dry land becomes one grade of green (Figure 14.5). You will see that the latter is not easy, as you have to think in negative values. It is easier to change the calculation to **Water depth = Floodtopo - Watersurf**. Do the calculation

FIGURE 14.5
Floodmap of Pais Pesca

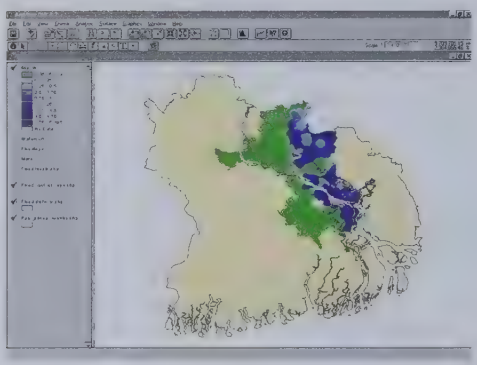
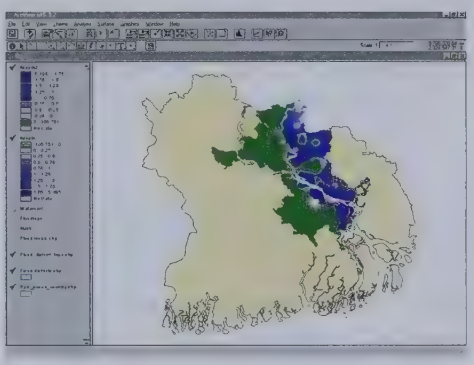


FIGURE 14.6
Floodmap of Pais Pesca, reversed calculation



again, but now first [Floodtopo]. Positive values signify dry land, while negative values become water depth (Figure 14.6). Save this Theme as 'fldepth2'.

4. You can save the project as: 'Pais Pesca floodmap.apr' in a folder you choose.

Note:

During calculation or grid manipulation you can get the following message:

This means that you have deleted grid files from the working directory. NEVER DO THIS! Always use Manage Data Sources in the File menu (via **File/Manage Data Sources...** in the menu bar, Figure 14.7). If you select this, the **Source Manager** window will popup (Figure 14.8) and here you can copy, move or delete grids.

[19] If you forget this the file(s) will have the name Calc1, Calc2, Calc3, etc.

FIGURE 14.7
Starting the Data Source Manager

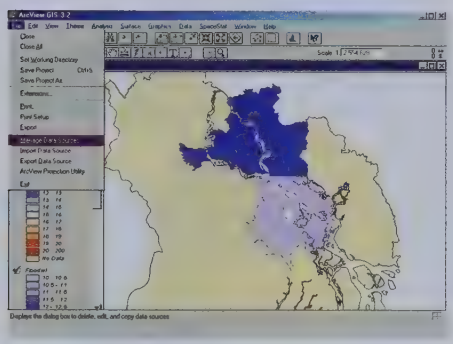
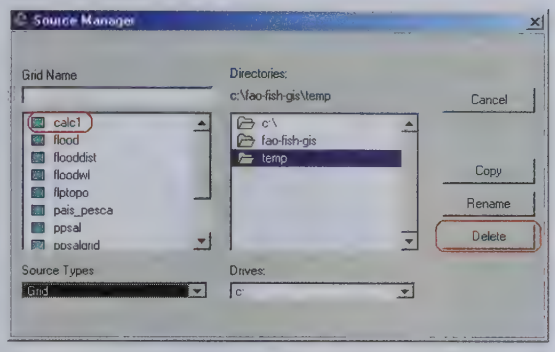


FIGURE 14.8
The Source Manager



14.2 RECLASSIFYING

The calculation of the water depth gives a large number of different water depths in the floodplain of Pais Pesca. However, in some calculations we are not interested in the water depth but only whether a certain area is flooded or not. Working with all the different water levels makes further calculations unnecessarily cumbersome. An easy way to overcome this problem is to reclassify the data, i.e. you give a specific value to all pixels representing a dry (0) area and another specific value (1) to all pixels that are flooded.

1. Continue where you stopped with the previous exercise, or open the project you saved: 'Pais Pesca Floodmap.apr'.
2. Activate the Theme 'Fldepth'.
3. Go to **Analysis/Reclassify...** via the menu bar (Figure 14.9); the **Reclassify Values** window will pop up. For the classification into dry and flooded we obviously only need two classes (dry and flooded).
4. Click on **Classify...** and select 2 classes in the **Classification** window (Figure 14.10) and click **OK**.
5. The **Reclassify Values** window appears again, now with two classes. All negative values that we calculated are dry areas, so you use the values -200 to 0 for dry land and the values 0 to 200 for flooded land. Click **OK** and the new Map will appear (Figure 14.11).

FIGURE 14.9
Opening the reclassify window

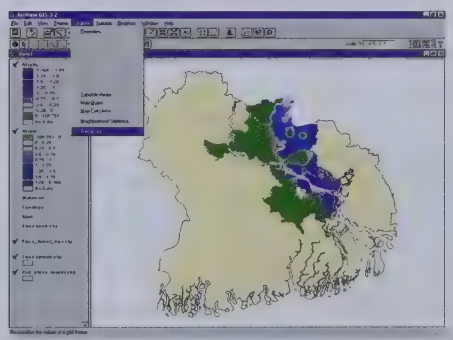
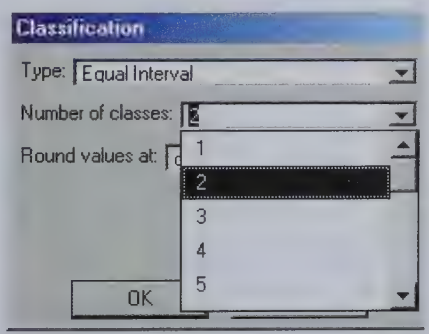


FIGURE 14.10
Selecting two classes to reclassify



6. Give the file a new name, arrange the legend (by double clicking the theme, or by going to **Theme/Edit Legend...**via the menu bar). If you have forgotten how to arrange a Legend, please have a look at Graphical displays in the Map View, on page 15.

7. Make yourself a flood map of June (Figure 14.12), and save the project again.

FIGURE 14.11
The new floodmap of Pais Pesca of October

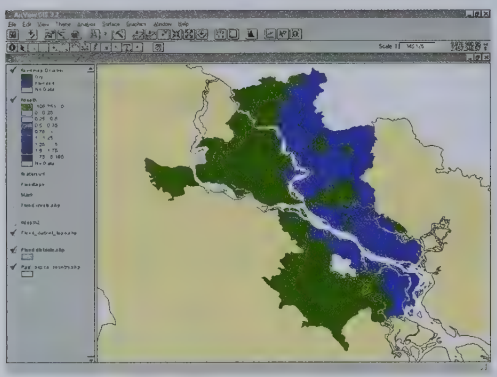
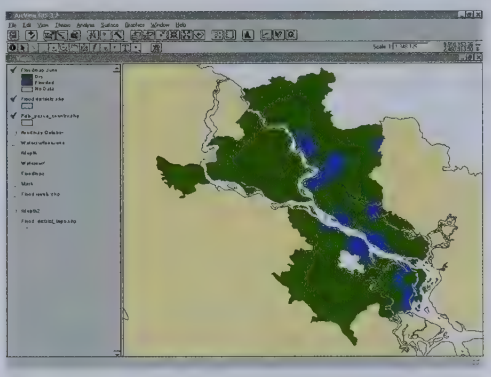


FIGURE 14.12
Floodmap of June



14.3 QUERYING

In a query, you try to find locations or areas on a map that fulfils certain criteria. This can be done with two criteria using two GIS Themes but it can also be a more complicated query using a large number of Themes.

Some examples:

- Find all the areas with a salinity level of 15 ppt and shrimp farming as a major crop. For this two GIS themes are needed, i.e. Salinity and shrimp farms.
- Find all the areas with alluvial soils, medium rainfall and rice as major crop. Here three themes are needed, i.e. soil map, rainfall map and land use map.
- Find all the villages with more than 50 percent fishers, more then 50 percent of Hindu house holds, average income of these households less then 150 $/year and fishing in the river. Four GIS themes are needed for this query, i.e. Occupation, Income, Religion, and Catching area.

14.3.1 Shrimp farming in the coastal areas of Pais Pesca

In the coastal provinces of Pais Pesca shrimp farming expanded rapidly from 8 000 ha in 1992 to 86 000 ha in 2001. The applied system[20] is extensive with low stocking densities of post larvae, mostly obtained from the wild. The system is an alternation of rice with shrimps, with rainfed rice during the wet season and one crop of shrimps during the dry season. Average yields of shrimps are in the order of 200–400 kg/ha/crop. However the expansion of shrimp farming was unplanned and three major problems developed over time:

- In the mid 1990s the first large problems with Monodon baculo virus (MBV) arrived followed by a serious outbreak of White Spot disease in 1998, which almost completely wiped out the shrimp production.
- Further due to the expansion and intensification of shrimp farming a serious conflict developed between the large shrimp farmers and the paddy farmers. This occurred as the shrimp farmers tried to grow two crops and consequently shrimp farming extended into the wet season resulting in a salt intrusion seriously hampering the cultivation of rice in the same area.
- Shrimp farming encroached into the mangrove forest, the major biosphere reserve of Pais Pesca. Shrimp ponds were constructed in acid sulphate soils in the mangrove area resulting in serious acidification of the surface water at the beginning of the rainy season.

[20] The species used is mainly *Penaeus monodon.*

In 2000 the Department of Fisheries carried out an extensive survey in the coastal area and collected the following information:

- Location and size of the shrimp farms;
- Average yields;
- Water quality;
- Disease occurrence.

You will make an analysis in GIS to demonstrate how grids and querying of different grids can be used to support management options for shrimp farming in Pais Pesca.

Shrimp farming analysis

The Ministry of Agriculture recommended reducing the number of shrimp farms in the agriculture zones of the coastal belt, i.e. the areas with low surface water salinities (5 ppt) in the dry season where paddy can be transplanted early in the rainy season. Therefore it requested the Department of Fisheries to give an indication of the consequences of this strategy.

1. Open ArcView, New Project, New View.
2. Set the working directory to a directory of your choice (for instance: C:\FAO_GIS\Temp), the projection of the View to 'Equal-Area Cylindrical', and the Distance and Map Units to meters.
3. Add the following Themes from the '13_Querying_shrimp' folder to the View: 'Pais Pesca country.shp', 'Shrimpfarms.shp', 'shrimp yields.shp' (all being Feature data sources), and the Grid data source 'Salgrid'. The folder contains also a legend for the salinity grid ('Salgrid') for use if you want to.

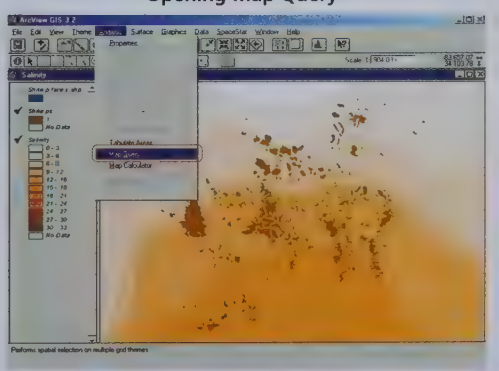
Salgrid is the same grid as you have made in the exercise on page 58. 'Shrimpfarms.shp' is a polygon file of all the shrimp farms in the coastal area of Pais Pesca. 'Shrimp yield.shp' a point file of the location of each farm, its average yields, and other data. 'Pais pesca country.shp' is a polygon file containing the outline of the country.

4. First you want to know how many shrimp ponds are located in the low salinity area. You can do this with a query between two grids. So first you have to convert the 'Shrimpfarms.shp' to a grid. You want to work in hectares so you choose a grid output CellSize of 100 m (resulting in an area of 100 m by 100 m = 1 hectare). Use the 'Id' field for cell values, and do not forget to rename the grid to 'shrimps'. To prevent this calculation to take too much time you might want to zoom in on the shrimp farms, and do the interpolation with the Output Grid Extent: Same As Display.

You need to query this shrimp grid with the salinity grid and use as selection criteria: **shrimp ponds = true, ([Shrimps] = 1.AsGrid]) and salinity <= 5 ([Salgrid] <= 5)**. In other words: of all the spots in the shrimp Theme where there is a farm present (or equal to the desired value of the pixels, in this case 1, as there is no other value), find the spots where the salinity (on the salgrid Theme) is equal or lower than 5 ppt.

5. Go to **Analysis/Map Query...** via the menu bar (Figure 14.13).

FIGURE 14.13
Opening Map Query



6. The **Map Query** window will pop up and you need to put the selection criteria in the window: **([Shrimps] = 1.AsGrid) and ([Salgrid] <= 5)**. You can do this in several ways: You can type this sentence in the lower window, or you can select the arguments from the top part of the Map Query window; First you double click on [Shrimps], then you click on '=', and then you click on '1'. When you have clicked on '1' you see in the query line appear: '1.AsGrid'. This is normal, but you can also use a number you put in yourself (like '1') which will also work. Then click on 'and' in the middle of the Map Query window, after which you double click on [Salgrid], '<=', and type '5'. You can not select '5' from the values part, so you have to type this value. (Figure 14.14). Click on **Evaluate**.

FIGURE 14.14
Selecting the criteria for the query

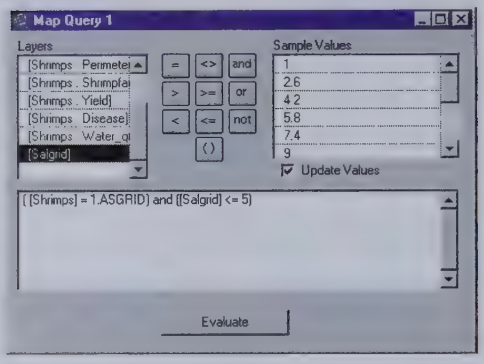
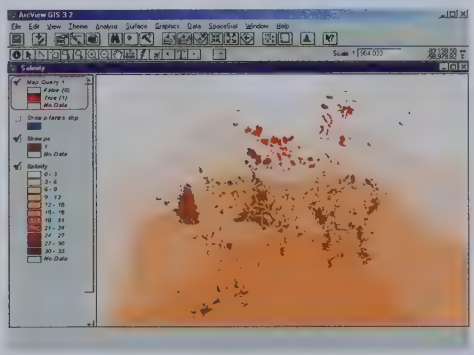


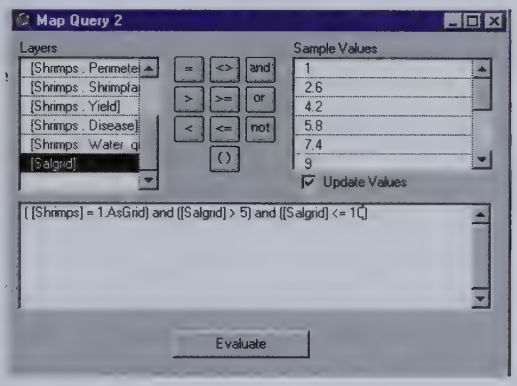
FIGURE 14.15
Results of Querying shrimp farms and salinity



7. The query will run and after some time the results of the query, which is called 'Map Query 1' will appear in the **View** (Figure 14.15). First close the Map Query 1 window, and then do not forget to save this query as 'SHRSAL5'[21] (**Theme/Save Dataset...**). If you open the Theme attribute table of the grid you will see that there are approximately 14 800 pixels of shrimp pond, meaning that 14 800 ha of shrimp ponds are located in the low salinity zone. We converted the original shapefile to a grid with a cell size of 100 metres by 100 metres, which is 1 hectare. If the number differs greatly from 14 800 you need to check the projection of the view, to make sure it is Equal Area Cylindrical.
8. To get a more clear picture you also want to know how many farms are located in the other zones and we make the query **Shrimp farms yes and 5> salinity<=10**. In other words, find the shrimp farms which are located in areas where the salinity is higher than 5 ppt and lower or equal to 10 ppt (Figure 14.16).

[21] Remember the naming convention!

FIGURE 14.16
Querying with two grids and three criteria



9. Fill in Table 14.2:

TABLE 14.2
Salinity and number of shrimp farms

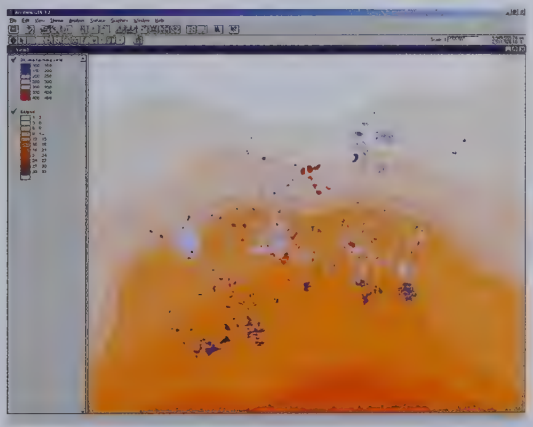
Salinity zone *(ppt)*	Shrimp farms *(ha)*
0-5	14 800
5-10	
10-15	
15-20	

You see that more then 50 percent of the farms are located in the salinity zone of 5–10 ppt. But still approximately 15 000 ha are located in the low salinity zone and the question is if you can get more information on the status of the farming system in this area before you decide to close them. For this you have to look at the yields of the farms. The location and the yields of the individual farms are available in the 'Shrimp yields.shp' Theme. This is a point shapefile so you can use it to generate a grid for the yields.

10. Make a surface grid of the yields (through interpolation, menu bar: **Surface/Interpolate Grid...**), Output grid size 100 metres, with the Shrimps grid set as mask. Remember that this might take a while! (To reduce the time, zoom in on the 'Shrimp yield.shp' Theme, and make the Output Grid Extent: Same As Display). After the interpolation is completed you can load a legend for this grid named 'shrimp_yield_grid.avl' (in the 13_Querying_shrimp folder).

If you do it correctly you will get a grid like the one presented in Figure 14.17.

FIGURE 14.17
Shrimp farming yield in the different salinity zones of Pais Pesca



The results change the picture somewhat. We see yields (blue) of about 150–250 kg/ha/crop in the northeast in the salinity zone of 0–3 ppt. In the zones of 3–12 ppt yields are in the order of 250–450 kg/ha/crop (light blue to red) and in the south you suddenly observe very low yields (dark blue) of 100–150 kg/ha/crop in salinities from 12–15 ppt.

A first conclusion could be to recommend to the Ministry of Agriculture to close the shrimp farms in the salinity zones of 0–3 ppt. Query again how many hectares of shrimp farms would be closed under this option[22]. Secondly you found another problem in the 12–15 ppt zone. The salinity levels are favourable for culture of *P. monodon*, so there must be another factor causing these very low yields in the southern part.

In the Theme table of the 'Shrimp farms' shapefile we have data on Shrimp diseases and water quality. With simple queries of this theme table you can select the farms with a 'high disease' occurrence, a 'low disease' occurrence, 'bad water quality', 'reasonable water quality', etc. Try this out (Remember: First you have to convert the Theme 'shrimpfarms.shp' into a grid (menu bar: **Theme/Convert to Grid...**), with a cell size of 100 metres, while picking the relevant Conversion Field, before you can query it in the Map Query).

You will find that the low production in the south is related to 'high disease occurrence' and 'bad water quality'. The question now is what is the cause of this problem.

Add the Theme 'Mangrove.shp'. You can see that the farms with the low productions are mainly located in the mangrove belt.

How many hectares of shrimp farm are located in the mangrove belt?

1. Convert the 'Mangrove.shp' Theme to a grid, with grid size 100 meters (Check your working directory and projection, zoom in on the Theme, and make the conversion Output Grid Extent: Same As Display).
2. Query the Mangrove grid with the Shrimp farm grid (Figure 14.18), which will give you Figure 14.19.

FIGURE 14.18
Querying the mangrove grid with the shrimp farm grid

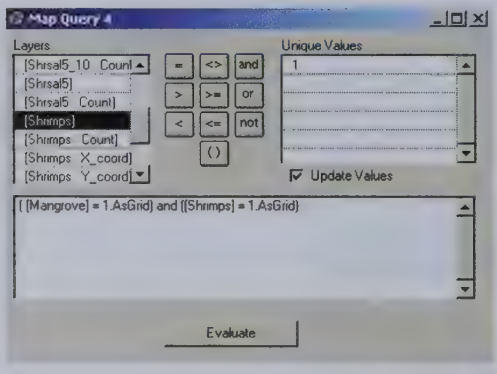
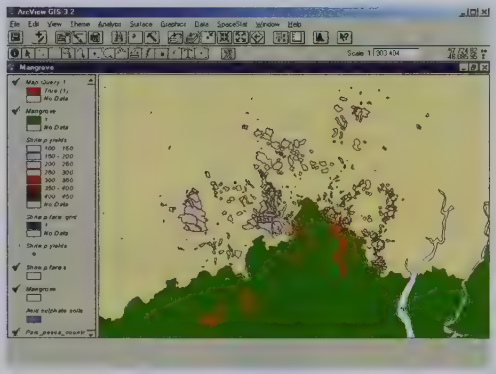


FIGURE 14.19
Shrimp farms in the mangrove forest of Pais Pesca



[22] This should be around 5 855 hectares.

From the Theme table of the Map Query Theme you see that approximately 15 589 pixels are selected with this query, meaning that 15 589 ha of shrimp ponds are constructed in the mangrove belt of Pais Pesca (as one cell is 100 metres by 100 metres). Query further the Mangrove grid with the surface grid of the yields, after which you will get the following distribution (Table 14.3):

TABLE 14.3
Area of shrimp ponds according to average yields in the mangrove belt of Pais Pesca

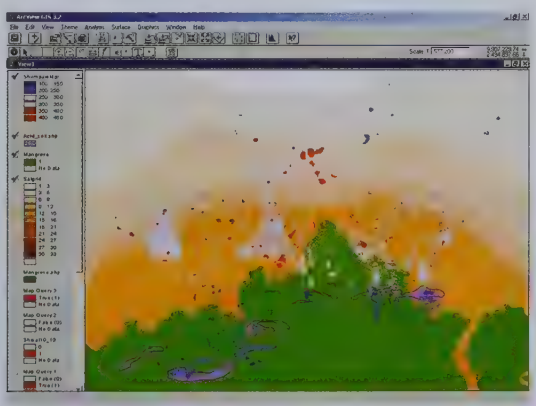
Shrimp yield *(kg/ha/crop)*	Area *(ha)*
100-150	1 236
150-200	7 098
200-250	444
250-300	2 245
300-350	3 312
350-400	1 214
400-450	37

From this distribution we see that 8 334 ha has low annual yields of 100–200 kg/ha/crop, this apart from the favourable salinity of this area. There must be a negative factor affecting the production (again, if your numbers are not the same as given in the table, check your projection, to see whether you use Equal-Area Cylindrical).

The major reason for the low productions, high disease rate, and bad water quality might be that ponds are constructed on acid sulphate soils. These soils are a normal phenomena in mangrove forests. No problems will arise if they are left undisturbed. However, disturbing them (by for instance digging ponds into these layers, or ploughing) results in leaching of sulphuric acid and a reduced pH of the surface waters (de Graaf *et al.*, 1998).

Add the 'Acid_soil.shp' Theme and this relation becomes clear (Figure 14.20). How many hectares of shrimp farms are constructed on acid sulphate soils? What would be your recommendation regarding the shrimp ponds in the low salinity areas and in the mangrove belt? Try to answer these questions by querying (do not forget to convert the 'Acid_soil.shp' Theme first).

FIGURE 14.20
Shrimp ponds, mangrove and acid sulphate soils in Pais Pesca



14.3.2 Protection of fish stocks and the creation of protected areas in Lake Kadim, Pais Pesca

Lake Kadim is the largest fresh water lake of Pais Pesca (220 km²). Fisheries at the lake is highly productive with an annual catch of about 2 000 metric tonnes/year and it provides an income to 1 300 professional fishers. There are two major fish species:

- *Carpio felixiensis*. A phytoplankton feeder, mainly living in water depth up till 10 metres, annual catch 900 metric tonnes.
- *Clupea pepeiensis* a pelagic, zooplanktivore, annual catches 700 metric tonnes.

The fishers demanded the creation of protected areas, where fishing is closed during the spawning season for protection of the stocks. However, they could not agree where to create the sanctuaries and asked the Department of Fisheries (DoF) for assistance. In 1999, an extensive survey has been carried out during the spawning season by DoF, to provide scientific data for selection of spawning sanctuaries. Systematic sampling was carried out all over the lake and the following data was collected:

- Water depth (m);
- Water temperature (°C);
- Secchi depth (m);
- Chlorophyll A (µg/l);
- Larval abundance clupeids (number/m²);
- Larval abundance of carp(number/m²);
- Abundance of adult carp (number/m²).

Analysis of the data in GIS will support the decision where to create fish spawning sanctuaries as it lets you understand the basic mechanisms behind spawning and spatial distribution of the adult fish and their larvae and eggs.

1. Open ArcView, New Project, New View.
2. Add the Themes 'Lake kadim data.shp' (containing all data and georeferences concerning the different sampling sites in Lake Kadim), 'Lake kadim boundary.shp', and 'pais pesca country.shp' from the '14_Lake_Kadim' folder.
3. Check the working directory and set the projection.
4. As you are going to work at Lake Kadim only, you will first need to make a grid of the 'Lake Kadim boundary' shapefile, output grid size 100 metres, so each pixel equals 1 hectare. Save this grid as 'kadimbnd'.
5. Set this grid as mask.
6. Activate 'lake Kadim data' and make a surface grid[23] (by interpolating) of the 'water depth' with 'IDW' and a 100 metres grid cell size. If you do this interpolation on the View it will take a long time, so Zoom in on Lake Kadim, and make the Output Grid Extent: Same As Display. Save the new grid as 'Kaddepth'.
7. Make similar surface grids for 'secchi depth', 'chlorophyll', 'adult carp abundance', 'carp larvae abundance', 'clupeids larvae abundance' and 'water temperature'.

[23] Also create this grid with Kriging see Annex C: Kriging on page 155.

The different grids are presented below, (Figure 14.21 until Figure 14.27). The first impressions are:

- The deeper parts are in the middle of the lake.
- Low Secchi disc, high chlorophyll concentration, high carp larvae density, high adult carp density and higher surface water temperatures are in the northwest of the lake.
- While the highest density of clupeid larvae is in the centre of the lake.

FIGURE 14.21
Water depth of Lake Kadim

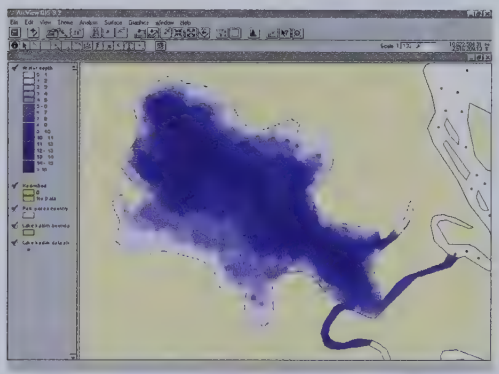


FIGURE 14.22
Secchi depth of Lake Kadim

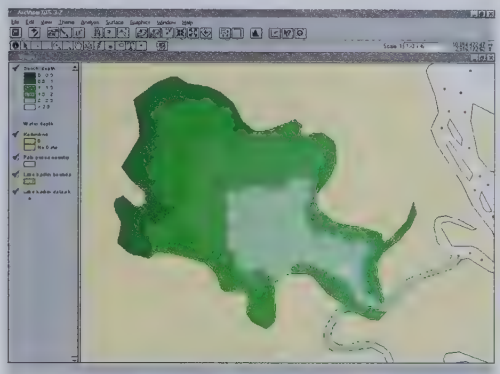


FIGURE 14.23
Chlorophyll concentration in Lake Kadim

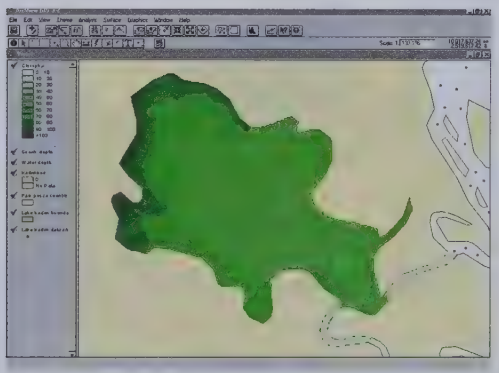


FIGURE 14.24
Carp larvae density in Lake Kadim

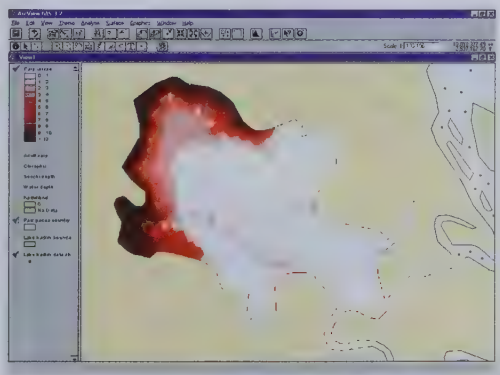


FIGURE 14.25
Clupeid larvae density in Lake Kadim

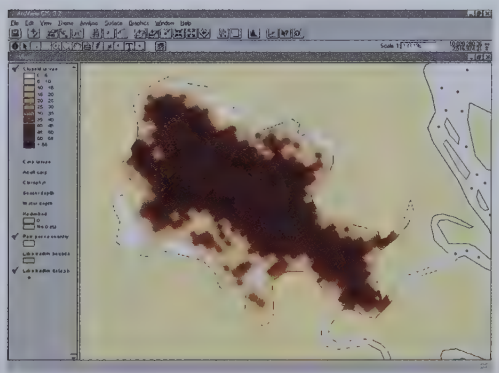


FIGURE 14.26
Adult carp density in Lake Kadim

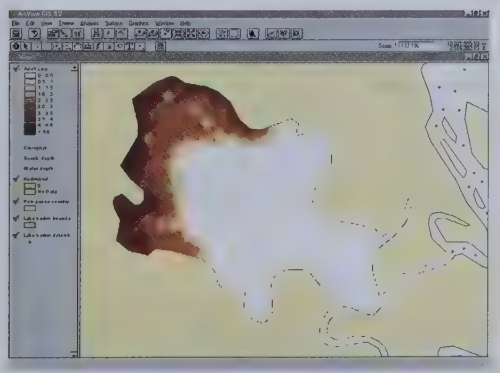
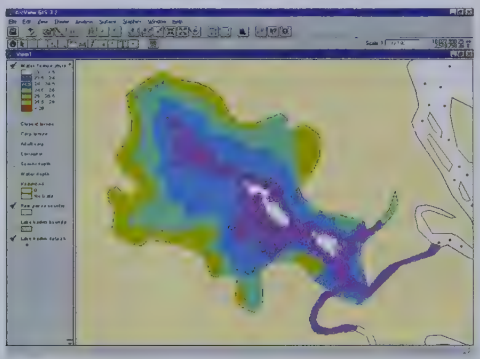


FIGURE 14.27
Water temperatures in Lake Kadim



However, these are only impressions. Check if an analysis in GIS can confirm the following hypothesis: Adult carp are mainly found in the shallow waters. For this you need to query the water depth grid with the adult carp grid (Figure 14.28). The results (Figure 14.29) show that there are adult carp in shallow water, but only in the northwestern part of the lake. In the shallow waters in the southeast, the densities of adult carp are low.

FIGURE 14.28
The query between water depth and adult carps

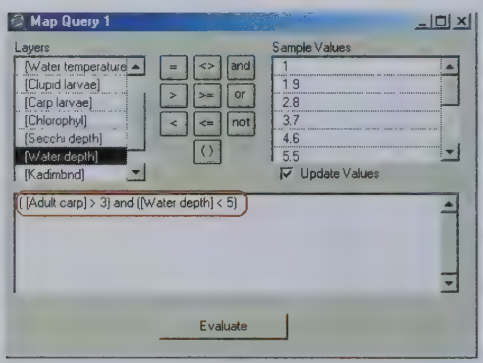
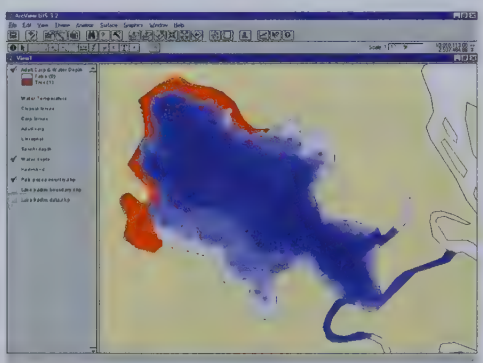


FIGURE 14.29
The results of the query between water depth and adult carps



Maybe adult carp prefer higher water temperatures. Therefore, query the adult carp grid with the water temperature grid (Figure 14.30). The results are presented in Figure 14.31.

FIGURE 14.30
The query between adult carps and water temperature

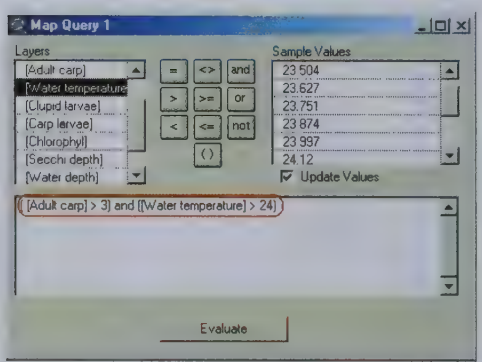
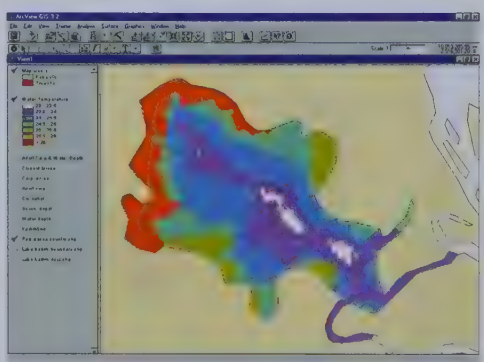


FIGURE 14.31
The results of the query between adult carps and water temperature



The carp is phytophageous so it could be that the abundance of phytoplankton is a factor in the distribution of the adult carp. Therefore, query the chlorophyll grid with the adult carp grid (Figure 14.32). The results are presented in Figure 14.33. Indeed you see a very good match between the chlorophyll and the adult carp distribution which could mean that chlorophyll or the abundance of phytoplankton is a major factor for the distribution of adult carp.

FIGURE 14.32
The query between adult carps and chlorophyll

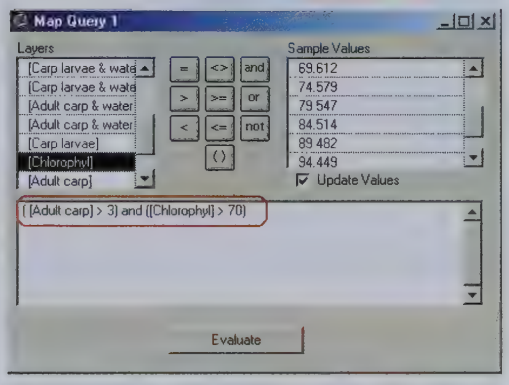
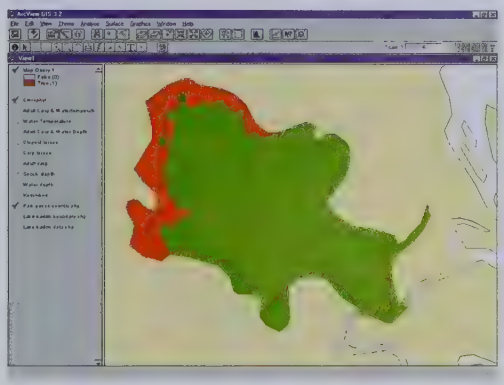


FIGURE 14.33
The results of the query between adult carps and chlorophyll



What about the distribution of carp larvae, would that be related to water temperature? Query the carp larvae grid with the temperature grid (Figure 14.34). The results are presented in Figure 14.35.

FIGURE 14.34
The query between carp larvae and temperature

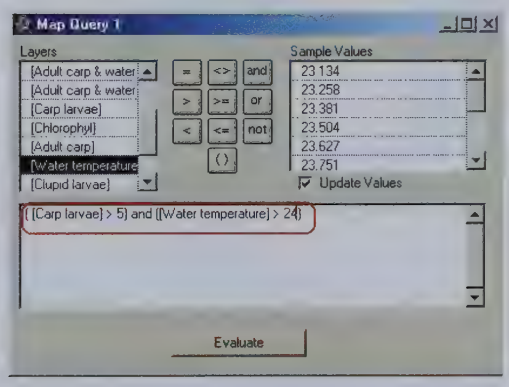
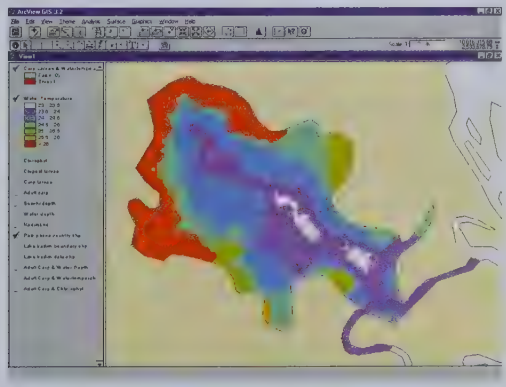


FIGURE 14.35
The results of the query between carp larvae and temperature



What about the water depth and the distribution of carp larvae? (Figure 14.36). The result of the query between the water depth and the abundance of carp larvae is presented in Figure 14.37. Again, you see shallow parts where there are no carp larvae, especially the northeastern and southern shorelines.

FIGURE 14.36
The query between carp larvae and water depth

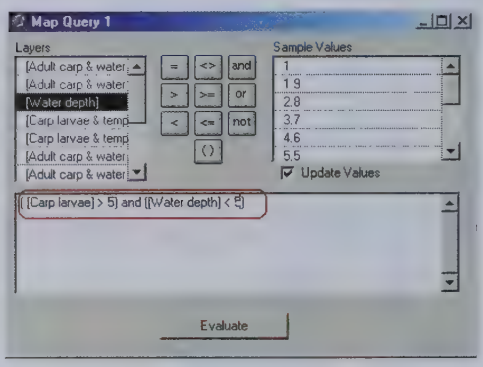
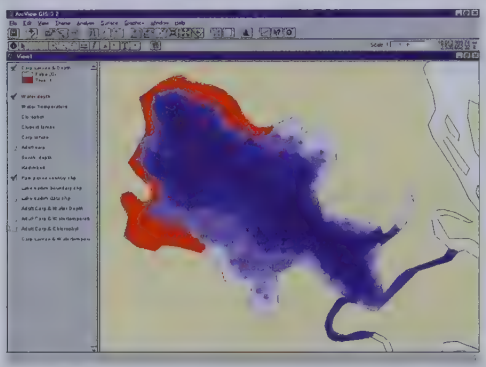


FIGURE 14.37
The results of the query between carp larvae and water depth



Query the carp larvae grid with the chlorophyll grid (Figure 14.38). The results are presented in Figure 14.39. What are your conclusions?

FIGURE 14.38
The query between carp larvae and chlorophyll concentration

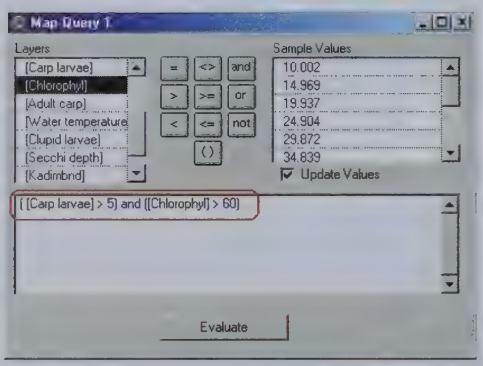
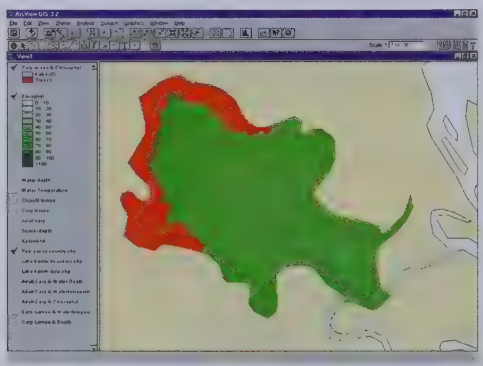


FIGURE 14.39
The result of the query between carp larvae and chlorophyll concentration



Query the carp larvae grid with the secchi depth grid (Figure 14.40). The results are presented in Figure 14.41. What are your conclusions?

FIGURE 14.40
The query between carp larvae and Secchi disk depth

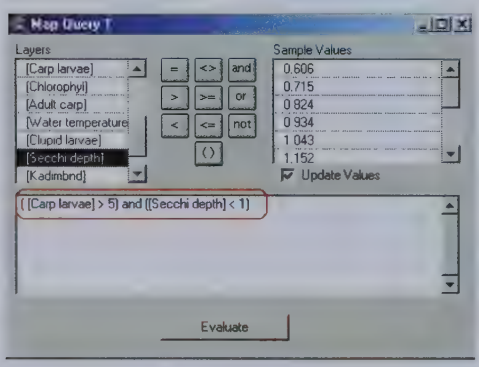
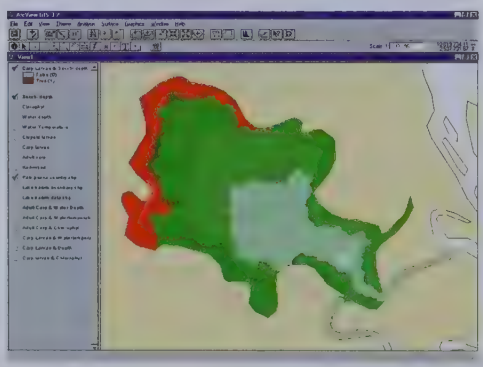


FIGURE 14.41
The result of the query between carp larvae and Secchi disk depth



A first look at the distribution pattern of the Clupeid larvae indicates immediately that this is not related to chlorophyll or secchi depth. However, it could be related to water depth or surface water temperature as the highest densities are found in the middle of Lake Kadim.

Query the 'clupeid larvae' grid with the 'water depth' grid (Figure 14.42). The results are presented in Figure 14.43. The created grid is reasonable but there are still high densities of clupeid larvae outside the created grid. Make the grid again but now with a water depth of 6 metres or more. Does this improve the situation?

FIGURE 14.42
The query between clupeid larvae and water depth

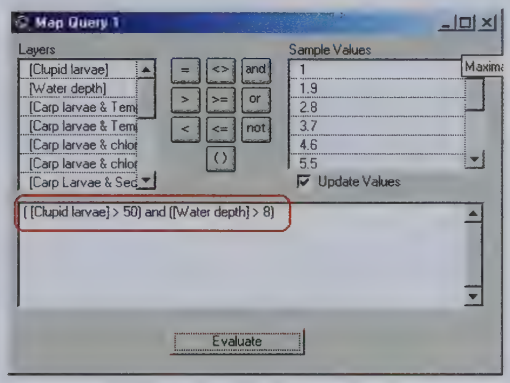
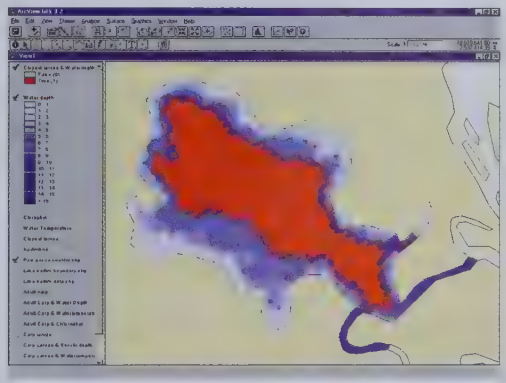


FIGURE 14.43
The results of the query between clupeid larvae and water depth



Query the Clupeid larvae grid with the water temperature grid (Figure 14.44). The results are presented in Figure 14.45. The created grid matches better then the water depth especially at spot points and it seems that water temperature, especially in the central part is an important factor for the distribution of clupeid larvae.

FIGURE 14.44
The query between clupeid larvae and water temperature

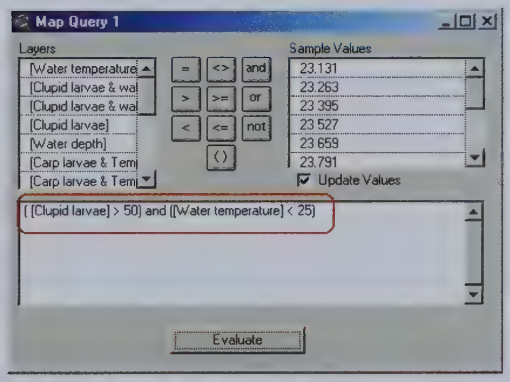
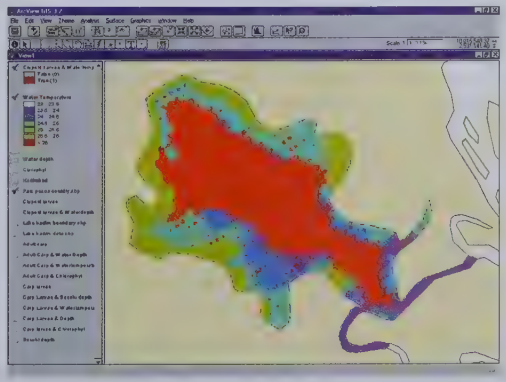


FIGURE 14.45
The result of the query between clupeid larvae and water temperature



Conclusions

- Adult *Carpio felixiensis* mainly concentrates in the shallow waters located in the northwestern part of Lake Kadim. The major driving force behind this mechanism is most likely feeding as its distribution follows the distribution pattern of chlorophyll. The newly born larvae of *Carpio felixiensis* follow the same distribution pattern.
- The larvae of *Clupea pepeiensis* have a completely different distribution as they aggregate in the deeper waters. In the deeper waters this distribution is most likely related to water temperature.

It should however be realized that the relations made visible through querying of grids is a kind of visualisation only. Direct relations between adult carp densities and chlorophyll or clupeid larvae and water temperature are not quantified or statistically verified. This can only be done through regression analysis and this will be discussed in the next chapter.

For the establishment of a fish sanctuary these findings have complications as closing fisheries in the northeastern shallow and eutrophic waters will certainly protect the carp stocks but this will not protect the clupeid stocks. Only a complete closure of fisheries for several months will protect both stocks.

15 Regression analysis

As indicated in the previous chapter (from page 59 onwards) querying of data grids in GIS can give you a first indication of relations between different factors. To get a more precise idea you have to carry out a statistical analysis on the available data. Regression analysis is a simple statistical tool to look at correlations between two or more types of data and is the most commonly used statistical technique in fisheries biology. First a refresher of the basic mathematics of regression analysis.

15.1 LINEAR REGRESSION

Linear regression is a technique to quantify the relationship, which can be seen in a graph made between two variables. For example, Figure 15.1 presents the relationship between the number of the fishers and the number of gillnets in the different villages around Lake Kadim. It shows you a relationship; when the number of fishers increases, the number of gillnets in the villages increases too, this is called **a positive relationship.**

FIGURE 15.1
The relation between the number of fishers and the number of gillnets in the different villages around Lake Kadim

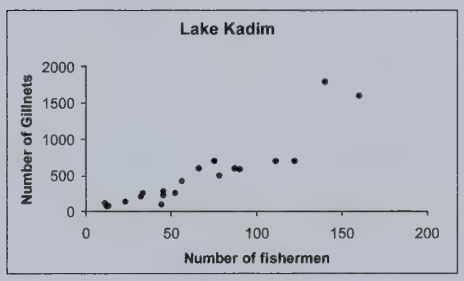
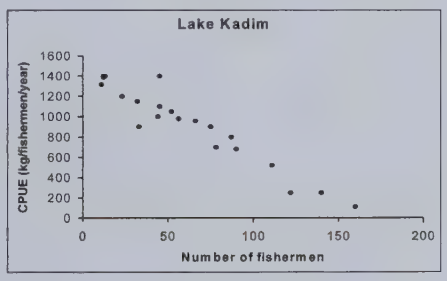


FIGURE 15.2
Relation between the number of fishers and their annual catch of carps



However, if you look at the annual carp catches of the individual fishers (Figure 15.2) you see a negative relationship where the catch decreases as the number of fishers increases.

It is nice to know that there is a positive linear relationship between the number of fishers and the number of gillnets at Lake Kadim, but our goal is to describe this relationship by a mathematical model or equation:

$$y = a + bx$$

In this equation **y**, the number of gillnets, is the variable on the vertical axis of the graph or the **dependent** variable, while **x**, the number of fishers, represents the variable on the horizontal axis or the **independent** variable. The value **a** (which can be negative, positive or zero) is called the intercept, while the value **b** (which can be positive or negative) is called 'slope' or 'coefficient of regression'. The question is how to calculate the values of **a** and **b**. You will not be bothered with the details but in all statistical textbooks you will see that **a** and **b** can be calculated with the following equations:

$$b = \frac{\sum xy - \left(\sum x \sum y\right)/n}{\sum x^2 - \left(\sum x\right)^2/n}$$

and

$$a = \bar{y} - b\bar{x}$$

Whereby;
x and y are the values of the different x and y pairs, n is the number of pairs, $\bar{y}$ is the average value of y, and $\bar{x}$ is the average value of x.
Have a look at the following data presented in Table 15.1.

TABLE 15.1
Data for the calculation of the regression between the number of fishers and the number of gillnets at Lake Kadim

Number of fishers x	No of gill nets y	x^2	y^2	x * y
12	90	144	8 100	1 080
33	260	1 089	67 600	8 580
140	1 800	19 600	3 240 000	252 000
160	1 600	25 600	2 560 000	256 000
45	230	2 025	52 900	10 350
111	700	12 321	490 000	77 700
87	600	7 569	360 000	52 200
75	700	5 625	490 000	52 500
66	600	4 356	360 000	39 600
122	700	14 884	490 000	85 400
11	120	121	14 400	1 320
44	100	1 936	10 000	4 400
52	260	2 704	67 600	13 520
56	420	3 136	176 400	23 520
32	210	1 024	44 100	6 720
12	75	144	5 625	900
45	286	2 025	81 796	12 870
78	500	6 084	250 000	39 000
90	585	8 100	342 225	52 650
23	140	529	19 600	3 220
13	82	169	6 724	1 066
$\sum x$ =1 307	$\sum y$ =10 058	$\sum x^2$ =119 185	$\sum y^2$ =9 137 070	$\sum xy$ =994 596
$\bar{x}$ = 62	$\bar{y}$ = 479			
n = 21				

Some basic calculations of means and sums are provided at the bottom of the table. Using these values and the formulas above, we can calculate our regression slope and intercept parameters:

$$b = \frac{994596 - \left(1307 * 10058 / 21\right)}{119185 - (1307)^2 / 21} = 9.7412$$

and $a = 479 - 9.7412 * 62 = -127.321$.

From this we can describe the relation; **y= -127.3 + 9.74x** or in words:
Number of gillnets = -127.3 + 9.74*Number of fishers.

Notice that the slope of the line (9.74) is a positive number, indicating that this is a positive relationship. This agrees with our visual interpretation of Figure 15.1.

In Table 15.2 the data for the number of fishers and their annual catch of carp (CPUE) is provided. Calculate the regression relation

TABLE 15.2
Relation between the number of fishers and the CPUE of carps in Lake Kadim

Fishers	CPUE	x^2	y^2	x * y
12	1 400	144	1 960 000	16 800
33	900	1 089	810 000	29 700
140	250	19 600	62 500	35 000
160	110	25 600	12 100	17 600
45	1 400	2 025	1 960 000	63 000
111	520	12 321	270 400	57 720
87	800	7 569	640 000	69 600
75	900	5 625	810 000	67 500
66	960	4 356	921 600	63 360
122	250	14 884	62 500	30 500
11	1 320	121	1 742 400	14 520
44	1 000	1 936	1 000 000	44 000
52	1 050	2 704	1 102 500	54 600
56	980	3 136	960 400	54 880
32	1 150	1 024	1 322 500	36 800
12	1 390	144	1 932 100	16 680
45	1 100	2 025	1 210 000	49 500
78	700	6 084	490 000	54 600
90	680	8 100	462 400	61 200
23	1 200	529	1 440 000	27 600
13	1 400	169	1 960 000	18 200
$\sum x$ =1 307	$\sum y$ =19 460	$\sum x^2$ =119 185	$\sum y^2$ =21 131 400	$\sum xy$ =883 360
$\bar{x}$ = 62	$\bar{y}$ = 927			
n = 21				

Result of the regression analysis: **y = 1 465 - 8.6627x.**

Nowadays regression analyses have become easier as they are included in all spreadsheet programmes such as Lotus 1–2–3 and Microsoft Excel. In Microsoft Excel regression analysis is carried out in graphs made with the datasets.

Lets do our Lake Kadim example in Microsoft Excel:

1. Start Microsoft Excel, Open the spreadsheet 'Lake Kadim regression analysis.xls', from the folder '15_Lake_Kad_regr'. You see the data set with the number of fishers, their CPUE, and two graphs.
2. Activate one graph by clicking on it.
3. Go to **Chart/Add Trendline** via the menu bar. The **Add Trendline** window will popup (Figure 15.3) and you select linear by checking its box. Then click the **Options** tab in the **Add Trendline** window and check **Display equation on chart** and **Display R-squared value on chart** (Figure 15.4). Click **OK.**

FIGURE 15.3
The Add Trendline window

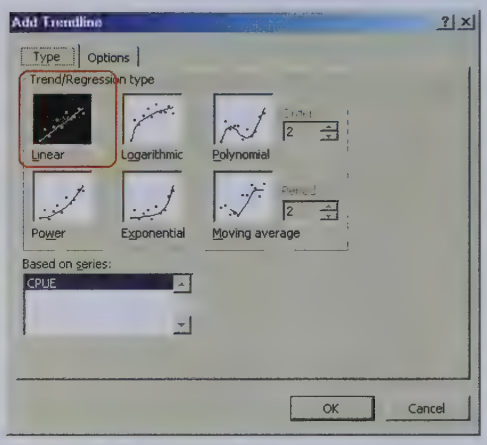
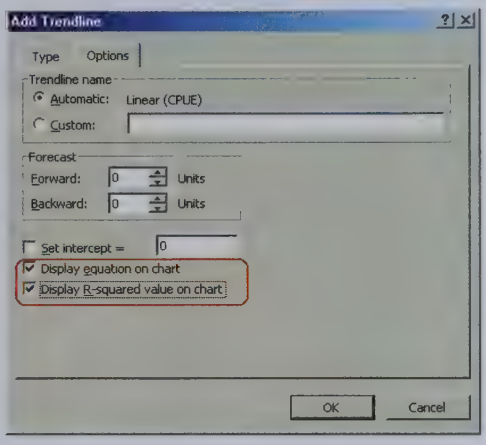
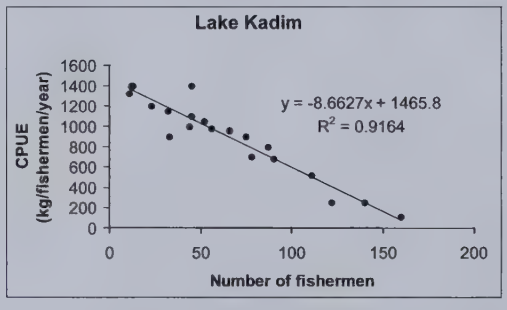


FIGURE 15.4
Checking Display equation on chart and Display R-squared on chart



The Chart of the graph is displayed again. Now with a straight line (the calculated regression) and the relation y = -8.6627x + 1465.8, which you calculated previously displayed in the chart (Figure 15.5).

FIGURE 15.5
The Microsoft Excel regression between the number of fishers and their CPUE in Lake Kadim



In the chart you also see another value: $R^2 = 0.9164$. R-squared, or the coefficient of determination, is the square of the correlation coefficient R. It is a measure of the linear association between two data sets and reflects the amount of variation in the dependent variable which can be explained by variation in the independent variable. R-square values value ranges between 0 (reflecting absolutely no linear relationship between the variables) and 1 (indicating a perfect correlation). For example if R-squared = 0.25, we could say that the variance in the independent variable explains 25 percent of the variation of the dependent variable. The closer to 1 the higher the correlation between the two variables will be. R-square is calculated as (Figure 15.6):

FIGURE 15.6
The equation to calculate R-squared

$$R^2 = \left(\frac{\Sigma(xy) - \frac{(\Sigma x)(\Sigma y)}{n}}{\sqrt{\left[\Sigma x^2 - \frac{(\Sigma x^2)}{n}\right]\left[\Sigma y^2 - \frac{(\Sigma y^2)}{n}\right]}} \right)^2$$

However a high value of R does not mean that the regression line is always statistically valid. The official way to look at this is to carry out a t-test on the regression coefficient b and test the calculated t-value, or to carry out an ANOVA (or Analysis Of Variance) and test the calculated value of the F-statistic. This can be done in any statistical software package.

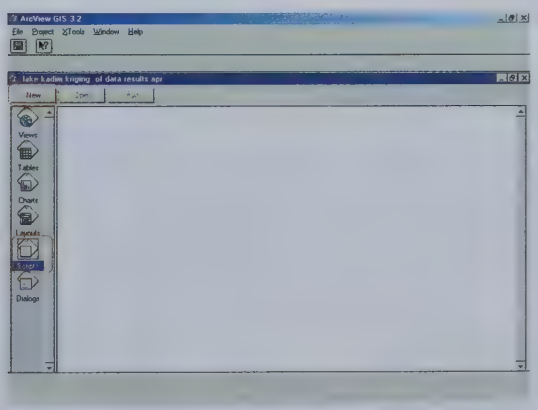
15.2 REGRESSION WITH AN AVENUE SCRIPT IN ARCVIEW

Unlike Microsoft Excel, regression analysis is not an integral part of ArcView. Fortunately, ArcView provides an internal coding language which allows us to write these type of functions. Many custom functions, including regression analysis, have already been written by ArcView users and are available for public use (for example see ArcScripts at http://gis.esri.com/arcscripts/index.cfm).

A sample regression script is included with the data on the CD which allows for linear regression analysis. The available method is rather basic, can only be applied on shapefiles and has a limited scatterplot function. This application will be shown to you using the example of Lake Kadim and carrying out a regression analysis between the number of fishers and the number of Gillnets in villages around Lake Kadim.

1. Start ArcView, Open a New Project, and a New View. Add to the View the Themes (from the '15_Lake_Kad_regr' folder): 'Pais pesca country.shp', 'Lake kadim boundary.shp', 'Lake Kadim data.shp' and 'Fishing village lake kadim.shp'.
2. Check the projection and the working directory.
3. First you have to add the script. Close the **View** and open a new script in the Project window (Figure 15.7).

FIGURE 15.7
Opening a new script



4. You arrive in the **Script** window, where you have to open the avenue script 'bvreg.ave' This is a text file and for your convenience it is placed in the same folder as the Theme file, '15_Lake_Kad_regr'. Go to **Script/Load Text File...** (Figure 15.8).
5. The load script window will appear. Go to the correct subdirectory and select the 'bvreg.ave' script and click **OK** (Figure 15.9).

FIGURE 15.8
Loading a script text file

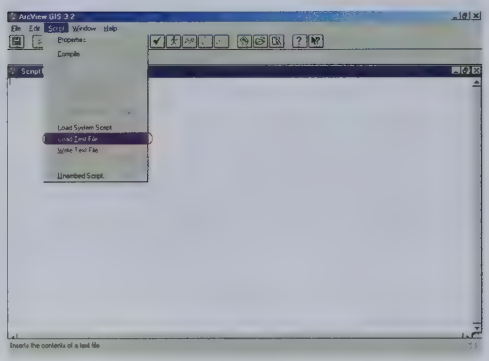
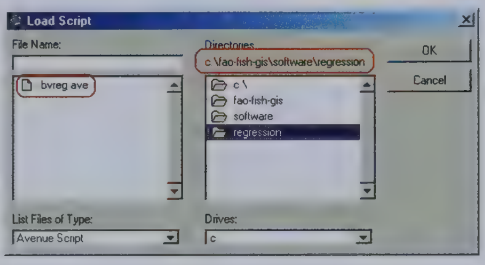


FIGURE 15.9
Selection of the regression script



For running the script you have to know some tricks. First you must compile the script. 'Compiling' simply means that ArcView checks the code text for errors and then converts the code into a format that ArcView can run directly. After you click the 'Compile button' (Figure 15.10) you will see the button next to it with the running person becomes active. This is the button for running the script. If you click on this button you will get an error message: 'A(n) project does not recognize request GetActiveThemes' (Figure 15.11).

FIGURE 15.10
Compiling a script

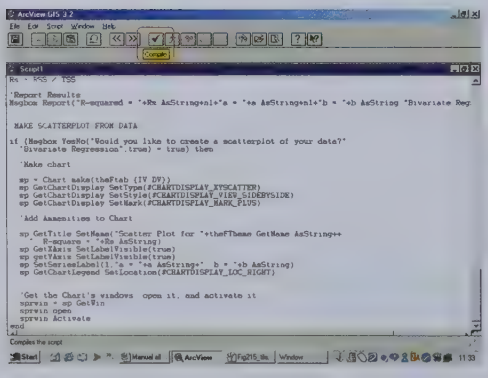
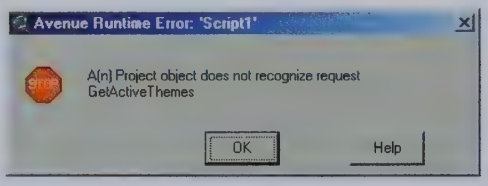


FIGURE 15.11
Regression error message



The basic reason we get this error message is that ArcView does not know where to look for the data to perform the analysis. The simplest way to tell it is to open the View, find the Theme which contains the data for the regression analysis, and make that Theme active. The way to do this seems complicated, but do not worry, it works and once you have done it several times you know the trick. Basically you have to tile the window so that the **View** and the **Script** window are visible. Then you can switch from one to the other.

6. Go in the script window to **Window/Tile** via the menu bar (Figure 15.12). You will get two windows on your screen. Open the view (Figure 15.13).

FIGURE 15.12
Tiling in the script view

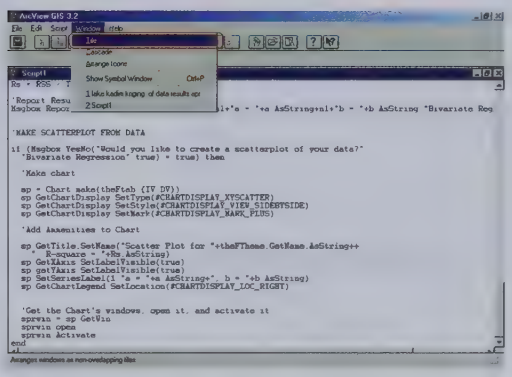
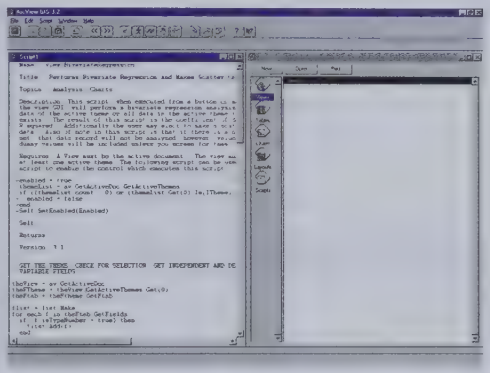


FIGURE 15.13
Tiled script and view window



7. After opening your View, tile the windows again via **Window/Tile** in the menu bar. You should now see three open windows in your project, and your View window should be your active window. You can see this because the window bar of this window is blue. Your View should have four Themes listed. Click on the words 'Fishing village lake kadim.shp' (not on the checkbox) to make the Theme active. Now ArcView will know which Theme contains the data for regression analysis (Figure 15.14).
8. Go back to the script window by clicking somewhere inside it, and then click on the **Run script** button (Figure 15.15).

FIGURE 15.14
Activating the data theme for regression

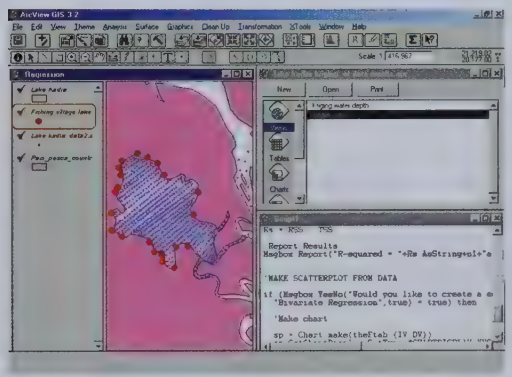
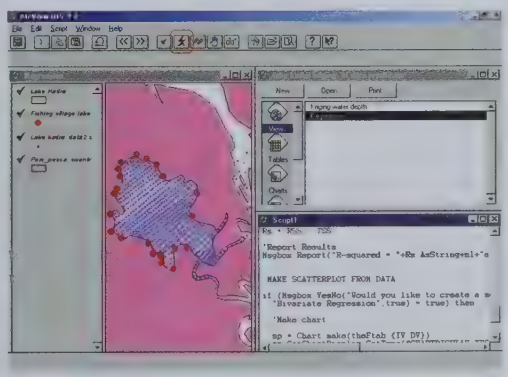


FIGURE 15.15
Running the script



9. The **Bivariate regression** window will appear. First you have to indicate the independent variable (X): 'Fishermen' (Figure 15.16), after selecting 'Fishermen'

FIGURE 15.16
Selecting the independent variable

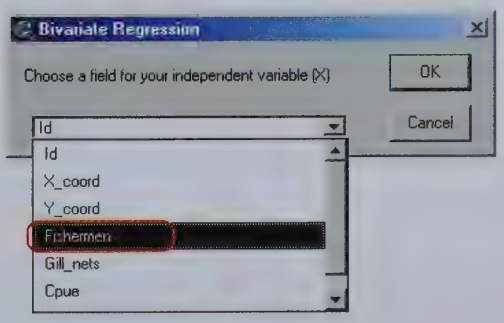
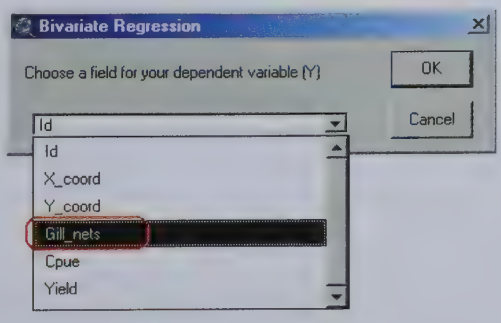


FIGURE 15.17
Selecting the dependent variable



click **OK.** In the next window you indicate the dependent variable (Y), 'Gill_nets' (Figure 15.17), and Click **OK.**

10. The **Bivariate regression results** window appears providing the results of the regression. In this case the results are similar to the calculation we made before, click **OK.** In the next window you will be asked if you want to create a scatter plot. Click **Yes** and the scatterplot with the calculated regression appears (Figure 15.19).

FIGURE 15.18
Bivariate regression results

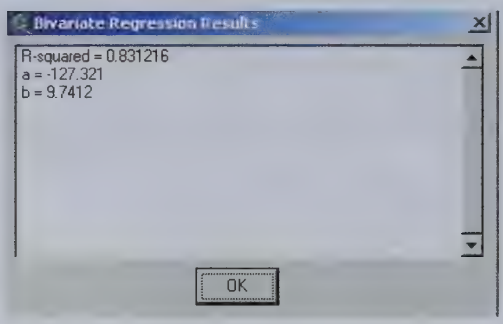
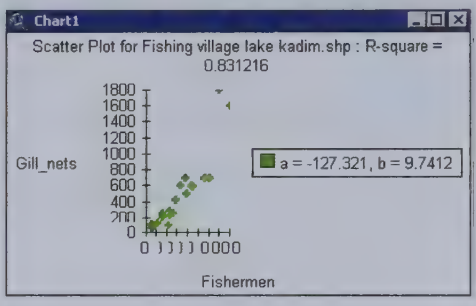


FIGURE 15.19
The scatterplot of the calculated regression



15.2.1 Regression analysis of Lake Kadim data using an avenue script

Make the regression analysis between the number of fishers and the CPUE with data from the theme 'Fishing villages of Lake Kadim' and compare them with the results of the analysis carried out in Excel.

Make a number of regression analyses with the data from the Theme Lake Kadim data and fill in Table 15.3.

TABLE 15.3
Results of regression analysis of the raw data of Lake Kadim

Parameters	a	b	R-square
Water depth - carp larvae			
Water depth - clupeid larvae			
Water depth - adult carp			
Water temperature - carp larvae			
Water temperature - clupeid larvae			
Water temperature - adult carp			
Chlorophyll - carp larvae			
Chlorophyll - clupeid larvae			
Chlorophyll - adult carp			

From this exercise you see that this script has limitations for the number of points in a scatter plot. The script works well if you want to make a quick regression between a small number of data. However, for a more profound analysis with large data sets it is easier to import the attribute table of the Theme into Excel and or into statistical software[24] such as SPSS, Minitab, Sysstat, or others, and carry out the analysis with these programs.

[24] Free statistical software can be downloaded at http://members.aol.com/johnp71/javasta2.html#General.

15.3 REGRESSION ANALYSIS BETWEEN GRIDS WITH THE GRID REGRESSION TOOL

Regression between grids can be very interesting, especially if we think about the application of the Munro and Thomson plot (1983b) for surplus production models in GIS as demonstrated by Corsi (2000a, a copy of the article can be found on the CD, folder 'Corsi_article'). These developments are very interesting, and will be discussed in the chapter: A Corsi type analysis of Hake data in the Mediterranean on page 130. However, as with the earlier example, there is no standard tool within ArcView to perform regressions between grids. The internet, at the time of writing this manual, also did not provide such a tool, so this tool called **Grid Regression**[25] was developed[26].

The Grid Regression extension carries out a regression analysis between pixels at the same location in two different grids. First each pixel at the same location in both grids is given the same Identification number and then the values of the pixels are attached to this ID number. Once this is done regression analysis becomes straightforward as we have an ID number each with a data pair (Figure 15.20).

FIGURE 15.20
Two grids with values for a regression

The Grid Regression extension has two modes of operation;

- **Vector based**, which means it is first generating a Point shapefile with separate fields for the Independent and Dependent values, then doing field calculations to generate the regression statistics.
- **Grid based**, which means the extension is directly multiplying and dividing the grids themselves.

The results of both modes are similar. The Grid based mode tends to go faster than the vector mode, while the vector mode produces more of the intermediate data such as seen in Table 15.1 and Table 15.2 on pages 78 and 79.

Install the extension by copying the file 'grid_regression.avx' from CD1 to your ArcView folder: '..AVGIS_30\ARCVIEW\ext32\' directory. Then, after you started ArcView, go to **File/Extensions...** via the menu bar and check the one called 'Grid Regression'. In your **View** screen, you should see now a new icon that looks a little like a blue regression line.

Grid regression of data from Lake Kadim with the Grid Regression extension

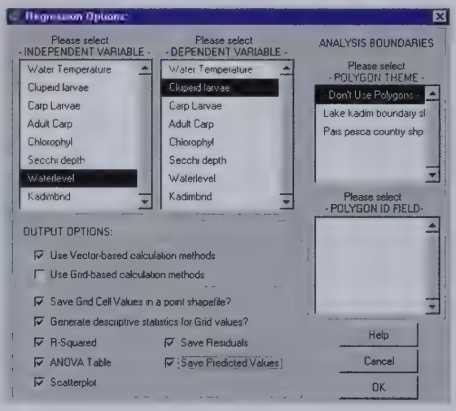
1. Copy the file 'grid_regression.avx' from the Extension folder on your CD to your ArcView '..AVGIS_30\ARCVIEW\ext32\' directory.
2. Open a **New Project**, New View. Check the projection (Equal-Area Cylindrical), working directory and properties settings (Distance Units: Meters).
3. **Add** the following Themes from the '16_Lake_Kad_regr_tool' folder from CD2 (with as Data Source Type: Grid Data Source): 'Kadimbnd', 'adultcarp', 'carplarvae', 'chlorophyll', 'clupeidlarvae', 'secchidepth', 'waterlevel', and

[25] The Grid regression tool can be downloaded at http://www.jennessent.com/arcview/arcview_extensions.htm.
[26] by Jeff Jenness, Jenness Enterprises, http://www.jennessent.com.

'watertemp'. Also **Add** the Themes (with Data Source Type: Feature Data Source): 'fishing village lake kadim.shp', 'lake kadim boundary.shp', 'lake kadim data.shp', and 'pais pesca country.shp'. Legends of all Grid Themes can also be loaded (from the same folder).

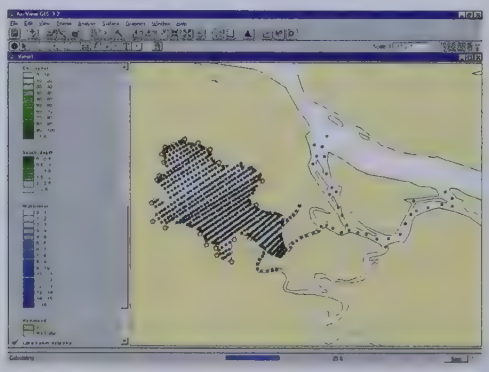
4. Go to **File/Extensions...** via the menu bar and activate the **Grid Regression extension.**
5. You see that all these Themes are the same as the ones you generated during the exercise: Protection of fish stocks and the creation of protected areas in Lake Kadim, Pais Pesca, on page 70. By querying the different grids you got an idea about the mechanisms behind fish distribution in Lake Kadim. Now check these ideas with the Grid Regression extension.
6. First the relation between water depth and Clupeid abundance. Open the Grid Regression extension by clicking the icon.
7. The **Regression Options** window appears (Figure 15.21). First you select the independent variable **Waterlevel**, then the dependent variable **Clupeidlarvae.** Do not use a boundary or barriers for your analysis, so in the - POLYGON THEME - box, select - Don't Use Polygons -.
8. Carry out a vector based analysis only, Check all the boxes as indicated in Figure 15.21, because all different parameters and grids need to be calculated and click **OK**.

FIGURE 15.21
The Regression Options window



At the bottom of the screen a regression analysis progress bar will appear (Figure 15.22).

FIGURE 15.22
The regression analysis progress bar



9. You will be asked where to save the files and give it a name. Do this and click **OK**.

FIGURE 15.23
The analysis progress window

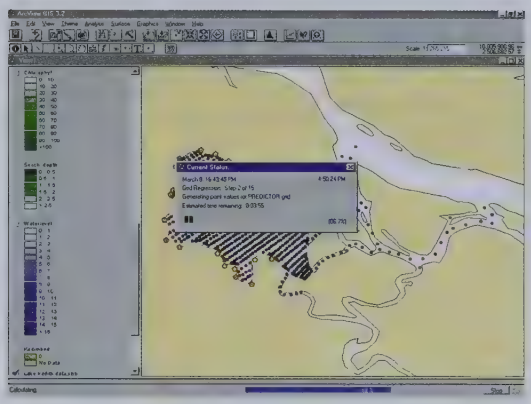
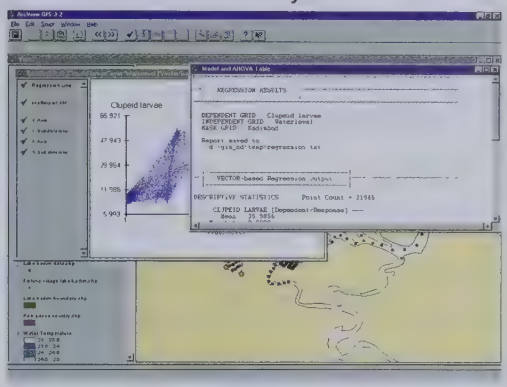


FIGURE 15.24
The model and ANOVA table, and the scatterplot of the analysis



After this the regression analysis progress window will appear (Figure 15.23). Here you can see which calculations are made and the progress of the analysis. The analysis will take some time, depending on the size of the grids. Different Themes will be automatically added to the **View** and the regression is finished once you see on your screen Model and ANOVA Table and the scatterplot of the analysis (Figure 15.24).

The results of the regression analysis are summarized in the Model and ANOVA table (Figure 15.25). It first indicates the grids used, and in your case you see (if you continued to work from page 70 onwards) that there was a grid used as a mask; 'Kadimbnd'. You used this grid as a mask during the interpolation of the different grids of Lake Kadim. In the present analysis you forgot[27] to remove this mask from the **Analysis Properties**.

[27] Or we forgot to instruct you to remove this mask.

Then the table presents the descriptive statistics of both grids used in the regression, and you see that the regression was carried out over 21 945 data pairs. Then follows the results of the linear regression: **y = 3.19x + 8.44** or **Clupeid abundance = 3.19*Waterlevel + 8.44** and the regression has an R-squared of 0.64, which is significant with P<0.000001.

FIGURE 15.25
The Model and ANOVA table

REGRESSION RESULTS

DEPENDENT GRID: Clupeidlarvae
INDEPENDENT GRID: Waterlevel
MASK GRID: Kadımbnd

Report saved to:
d:\tempgis\regression11.txt

VECTOR-based Regression Output:

DESCRIPTIVE STATISTICS: Point Count = 21945

— CLUPEIDLARVAE [Dependent/Response] —
Mean: 35.9856
Minimum: 0.0000
Maximum: 59.9283
Range: 59.9283
St. Dev: 20.4133
Variance: 416.7048
Sum: 789702.9801

— WATERLEVEL [Independent/Predictor]—
Mean: 8.6259
Minimum: 1.0000
Maximum: 18.9850
Range: 17.9850
St. Dev: 5.0995
Variance: 26.0051
Sum: 189295.9068

Regression Equation: y = 3.19360942915287x + 8.43784442507026
r-squared = 0.63649410816402

ANOVA Table
Dependent Grid: Clupeidlarvae

	Df	Sum of Sq	Mean Sq	F-Value	P-Value
Waterlevel	1	5820209.831	5820209.8308491	38421.9087682	0.0000000
Residuals	21943	3323959.387	151.4815379		
Total	21944	9144169.218			

Report Generated Tuesday, May 28, 2002 12:35:37

If you close the Model and ANOVA table you see the scatterplot of the 21 000 pairs of depth and clupeid density used in the analysis (Figure 15.26). From this figure you see immediately there is a positive relation. The higher the waterdepth, the higher the density of clupeid larvae. The red line represents the values of the calculated regression. It fits the values reasonably but from the scatterplot and the calculated regression you see also that a more S-like regression fit would provide better results as the highest values of the clupeid density tends to reach an asymptote. In principle your fit overestimates somewhat all low waterdepths and underestimates somewhat at medium waterdepth around 10 metres.

The Grid Regression extension only performs a linear regression. The data set is saved in your project and can be imported in any statistical or curvefit software. For example, a simple logarithmic plot carried out in Excel improves R-square already somewhat (Figure 15.27).

FIGURE 15.26
Scatterplot between Depth and Clupeid made with the Grid Regression extension

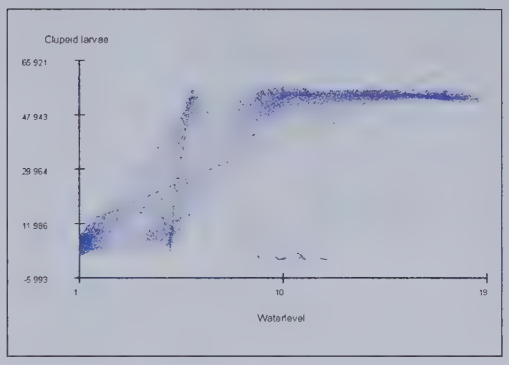
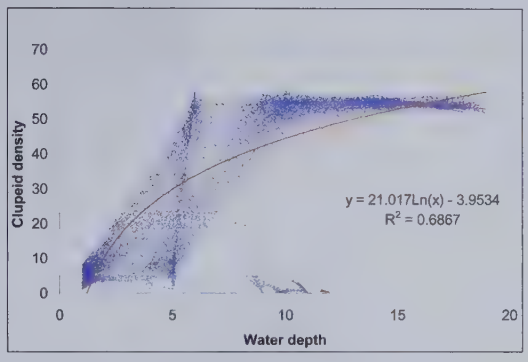
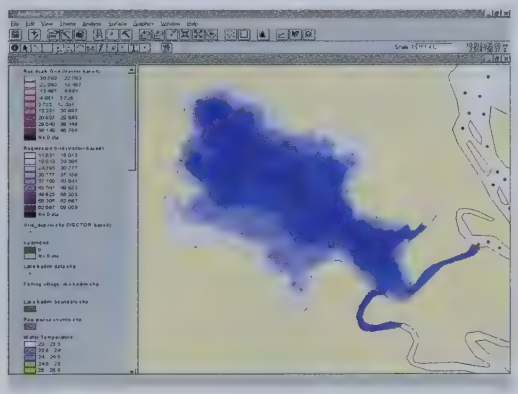


FIGURE 15.27
Scatterplot between Depth and Clupeids made in Microsoft Excel



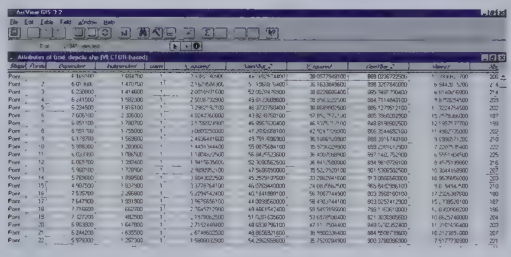
If you open the **View** again you see that the Grid Regression extension has added 3 themes to the View (Figure 15.28); the 'Grid_depclu.shp (VECTOR – based)' (this name depends on the name you have given the Grid values shapefile in the beginning), the 'Regression grid (Vector based)' and the 'Residuals grid (Vector based)'.

FIGURE 15.28
Themes added by the Grid Regression extension to View



The 'Grid_depclu.shp (VECTOR – based)' – Theme consists of a set of points located at the cell centres of the grids, and contains all the data from the grids. If you open the attribute table of this Theme (Figure 15.29) you see the different columns with the data for each pixel pair; 'Independent' which in this case is the water depth; 'Dependent', the Clupeid density; 'model', which is the expected Clupeid density value, given the regression model that was calculated by the Grid Regression extension, and 'Residuals', which is the difference between the expected Clupeid density and the actual Clupeid density.

FIGURE 15.29
The attribute table of the data used in 'Grid Regression'



'Regression grid (vector based)' contains the calculated values of the Clupeid density for each pixel and the 'residuals grid (vector based)' contains the residual for each pixels. Both grids and the scatterplot allow you to get an idea of the reliability of the calculated regression. The original data (clupeid density), water depth, the calculated values, and the residuals are plotted in Figure 15.30, Figure 15.31, Figure 15.32, and Figure 15.33). From the results you see that the calculated distribution follows the real distribution reasonably well. From the residuals you see that the major difference is found in the medium water depth (6–12 metres), where the density is underestimated which you saw already from the scatter plot (Figure 15.26).

FIGURE 15.30
Clupeid density in Lake Kadim (original measurements)

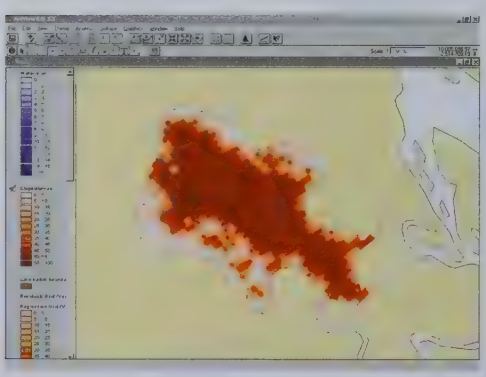


FIGURE 15.31
Water depth of Lake Kadim

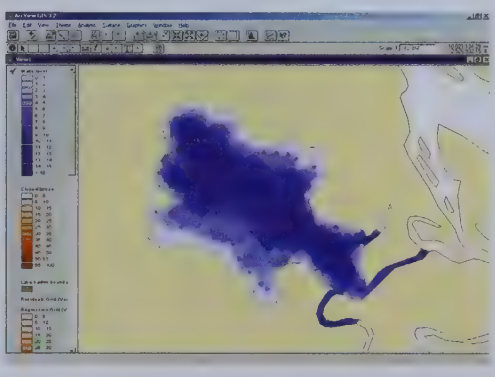


FIGURE 15.32
Calculated clupeid density (Model)

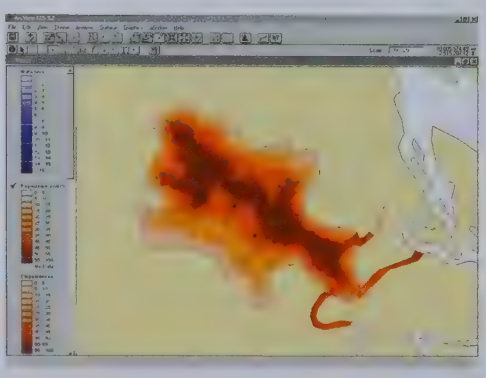
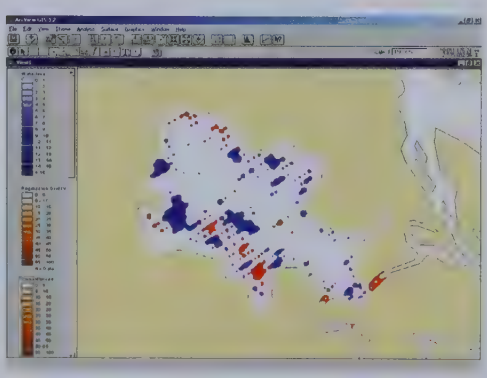


FIGURE 15.33
Residual plot between the original and calculated densities



15.3.1 Grid regression of data from the fish survey at Lake Kadim

Make regression analysis between the different data grids of Lake Kadim and fill in Table 15.4 Results of the Grid regression between the different data grids of Lake Kadim.

TABLE 15.4
Results of the Grid regression between the different data grids of Lake Kadim

Parameters	a	b	R-square	Acceptable
Water depth - carp larvae				
Water depth - clupeid larvae	8.47	3.19	0.634	Yes
Water depth - adult carp				
Water temperature - carp larvae				
Water temperature - clupeid larvae				
Water temperature - adult carp				
Chlorophyll - carp larvae				
Chlorophyll - clupeid larvae				
Chlorophyll - adult carp				

Attention!: A warning about grid regression:

Although the above examples illustrate the usefulness and utility of grid regression, it should be noted that some aspects of it may violate some of the assumptions of basic regression statistics. The end results of these violations would likely be that your estimated parameters (i.e. your slope, y-intercept and R-square values) are probably a little bit off, and in particular your R-square value is likely to be slightly less than the calculated value. This may not be a problem in many cases because it is still a good method for identifying relationships between our independent variable and our predictor variables, and therefore helps us to predict what our independent variable will likely be doing in different areas based on our predictor variables. We do, however, have to be careful to report that there is some uncertainty about our model because of these violations, and be cautious when our R-squared value is near the limits of what we consider to be significant.

In particular, the violations are:

- *We did not measure at every point*: The fact that we are using grids usually implies that we know more about our independent variables than we actually do. We are regressing data using sample points that completely cover the entire area, and it is rare that we have actually measured all our variables at every one of these sample points. In fact, grids are generally created by some interpolation method in which values are only measured at a few points, and the rest of the region is estimated (or interpolated) based on the values at these sample points. Different grids may even be generated from different sets of sample points, at different resolutions, or by different interpolation methods. Therefore we are often not as certain of the true variable values at each sample point as we would be if we actually measured at that point.
- *Lack of Independence*: Most statistical techniques assume that each sample point is independent of the others, such that the values you measure at that point are completely unrelated to those points around it. This is not the case with most spatial phenomena, however, and it is even more pronounced with grid data. In fact, the interpolation methods often used to generate grids rely on the fact that locations near a point are likely to be more similar to that point than locations farther away, and the interpolation process uses that relationship to estimate what the values should be in the locations that were not measured. The concept that points close to each other are often more similar than points that are far away is referred to as 'spatial autocorrelation', and the degree to which a dataset is spatially autocorrelated can actually be useful information in its own right.

Additional Reading:

For those students who would like to learn about regression in depth, there are many texts available that cover it thoroughly. Two such texts that the authors recommend are:

- Applied Linear Statistical Models, 4th ed. by Michael H. Kutner, Christopher J. Nachtschiem, William Wasserman and John Neter (1 408 pages, published by McGraw-Hill/Irwin, 1996).
- Applied Regression Analysis, 3rd ed. By Norman R. Draper and Harry Smith (706 pages, published by Wiley-Interscience, 1998).

For those students who would like to learn more about spatial autocorrelation, some of the classic references are:

- Spatial Statistics, by Brian D. Ripley (252 pages, published by Wiley Series in Probability and Mathematical Statistics, 1981).
- Spatial Autocorrelation, by A.D. Cliff and J.K. Ord (178 pages, published by Pion Limited, 1973).
- Spatial Processes: Models and Applications, by A.D. Cliff and J.K. Ord (266 pages, published by Pion Limited, 1981).

16 Use of ArcViews' help and other ways to expand your knowledge

This manual by no means covers all possibilities of GIS, it merely touches upon the most important features for fisheries management. To get deeper into a subject, or explore a new possibility several ways are available to explore:

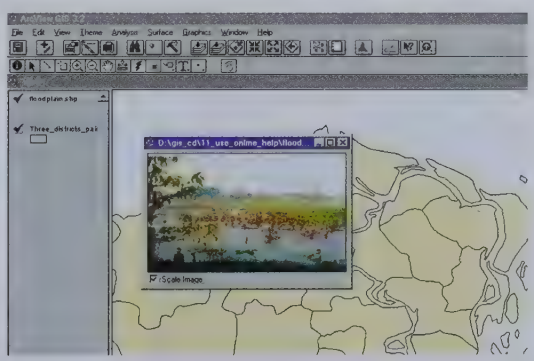
- Internet sources: http://www.fao.org/sd/eidirect/gis/EIgis000.htm, http://www.esri.com/, etcetera.
- Reference books.
- ArcViews' help.

The ArcViews' help is quite complete, and can be accessed through the Menu bar: **Help**. The following exercise will introduce you to the use of the ArcViews' help function.

It is possible to link images to Themes in ArcView. You need to find out how to link a floodplain picture to a map of three districts of Pais Pesca.

1. Start ArcView, Open a New Project, Open a New View. Check the working directory and the projection.
2. Add the Themes: 'three_districts_pais_pesca.shp' and 'floodplain.shp' from the folder '17_use_online_help'. The Theme 'three_districts_pais_pesca.shp' is a map of three southern districts of Pais Pesca, the Theme 'floodplain.shp' is a point Theme, showing the location where the picture 'floodplain.bmp' has been taken. You need to make a connection between this point and the picture, so that when users click on this point, the picture will be shown.
3. Find out how to link images to a theme through the ArcViews' help (menu bar: **Help/Help Topics..., Find** tab). Type 'link image' into the text box '1) Type the word(s) you want to find', and you will see in the box '3) Click a Topic, then Click Display': 'Defining a hot link for a Theme'. Click on this line and then on the button **Display**.
4. A window opens with the explanation on how to make a 'hot link'. Make this in such a way, that when you click on the point of the Theme 'floodplain.shp' with the hotlink pointer, the picture 'floodplain.bmp' will pop up (Figure 16.1).

FIGURE 16.1
The result of clicking the 'floodplain.shp' point Theme with the Hotlink pointer



17 Application case studies

17.1 REAL WORLD EXERCISES

17.1.1 World fisheries statistics

The Fisheries Department of the Food and Agriculture Organization of the United Nations keeps track of fisheries productions throughout the world. This data is stored in the FISHSTAT program. A copy is available through:

1. The world wide web: http://www.fao.org/fi/statist/FISOFT/FISHPLUS.asp.
2. E-mail: FIDI-Inquiries@fao.org.
3. Normal mail: Senior Fishery Statistician, FIDI, FAO, Viale delle Terme di Caracalla, 00100 Rome, Italy.

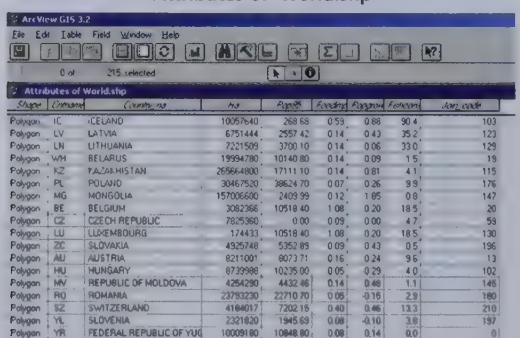
Obviously the preferable way to get the program is to download it from the internet, so that you can work with the data immediately and have the most up to date data. A summary file has been compiled for use with this manual (the file 'world fisheries production.dbf', in the folder: RW_01_World_fisheries). This file contains the following fields:

- Joincode (a number, specific to the country);
- Country (containing the country names);
- Total (containing the total fisheries production of the country [all data in this file concern with the year 1999 and are in metric tonnes]);
- Inland_cap (containing the inland capture fisheries production of the country);
- Marine (containing the marine capture fisheries production); and
- Aquacultur (containing the aquaculture production of the country).

Join this file to the Theme 'World.shp' (in the folder: 'RW_01_World_fisheries'). The 'World.shp' Theme contains the world map that was used during the World Food Summit in 1995. Per country the map contains one polygon. Furthermore the file contains per country the following data (fields), among others:

- Shape (here a polygon);
- Cntname (unique abbreviation of the country name);
- Country_name;
- Ha (the total area of the country, including economical zones, in hectares);
- Pop95 (estimated size of population in 1995);
- Join_code (a unique number specific to the country, equal to the joincode number in World fisheries production.dbf) (Figure 17.1).

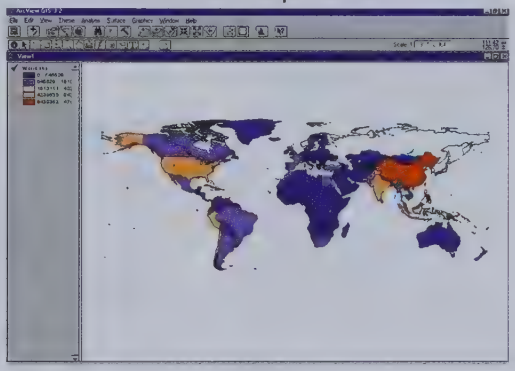
FIGURE 17.1
Attributes of 'World.shp'


ArcView GIS 3.2
File Edit Table Field Window Help
0 of 215 selected
Attributes of World.shp
Shape Cntname Country_na Ha Pop95 Fcondpct Fpopulpct Fcontpct Join_code
Polygon IC ICELAND 10057640 268 68 0 59 0 88 90 4 103
Polygon LV LATVIA 6751444 2557 42 0 14 0 43 35 2 123
Polygon LN LITHUANIA 7221509 3700 10 0 14 0 06 33 0 129
Polygon WH BELARUS 19994780 10140 80 0 14 0 09 1 5 19
Polygon KZ KAZAKHSTAN 26564800 17111 10 0 14 0 81 4 1 115
Polygon PL POLAND 3046752O 38624 70 0 07 0 26 9 9 176
Polygon MG MONGOLIA 15700600 2409 99 0 12 1 85 0 8 147
Polygon BE BELGIUM 3082366 10518 40 1 08 0 20 18 5 20
Polygon CZ CZECH REPUBLIC 7825360 0 00 0 09 0 00 4 7 59
Polygon LU LUXEMBOURG 174433 10518 40 1 08 0 20 18 5 130
Polygon ZC SLOVAKIA 4925748 5352 89 0 09 0 43 0 5 196
Polygon AU AUSTRIA 8211001 8073 71 0 16 0 24 9 6 13
Polygon HU HUNGARY 8739988 10235 00 0 05 0 29 4 0 102
Polygon MV REPUBLIC OF MOLDOVA 4254290 4432 46 0 14 0 46 1 1 148
Polygon RO ROMANIA 23793230 22710 70 0 05 -0 16 2 9 180
Polygon SZ SWITZERLAND 4184017 7202 15 0 40 0 46 13 3 210
Polygon YL SLOVENIA 2321820 1945 69 0 09 -0 16 3 8 197
Polygon YR FEDERAL REPUBLIC OF YUG 10009180 10848 80 0 08 0 14 0 0 0
Polygon UZ UZBEKISTAN 41311260 22843 00 0 14 1 97 1 2 234

Add the Theme 'World.shp', open the attributes table and verify whether or not you see all fields mentioned above. Add the file 'world fisheries production.dbf' to the tables, open it and check whether or not all above mentioned fields are there. Now we are ready to join 'attributes of World.shp' and 'world fisheries production.dbf'. Join both tables with the Joincode and Join_code fields. (remember that the 'world fisheries production.dbf' file is the file that contains the data [the **source table**] you want to join). If you do not remember how to join tables, please review chapter Joining data with location on a map, on page 23.

After joining both tables, go to View and have a look at the map (Figure 17.2). Change with the legend editor the legend type into **Graduated Color**, with as classification field **Total** and **Blues to Oranges dichromatic** in the color ramp. By doing this the result will be a world map with the countries with the lowest fisheries production in Blue and the countries with a high fisheries production in Orange.

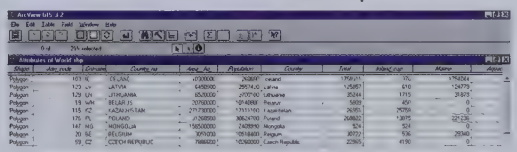
FIGURE 17.2
World fisheries production



Filtering

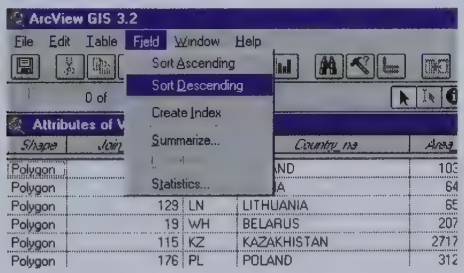
The produced map shows clearly that China had the highest fisheries production in the world in 1999. Have a look at the data in more detail. Open the 'Attributes Table of

FIGURE 17.3
Attributes of 'World.shp'



World.shp' (Figure 17.3) (either by pressing the Attributes button in the Tool bar, or by going to the project screen [close the view window], clicking on the tables icon, and then clicking on 'Attributes of World.shp'). After opening the 'Attributes of World.shp' table we'll see:
You need to sort the data according to Total fisheries production. First press the field heading 'Total'. Now sort the data descending, so that China will be on top of the list. Click on **Field/Sort Descending** via the menu bar (Figure 17.4).

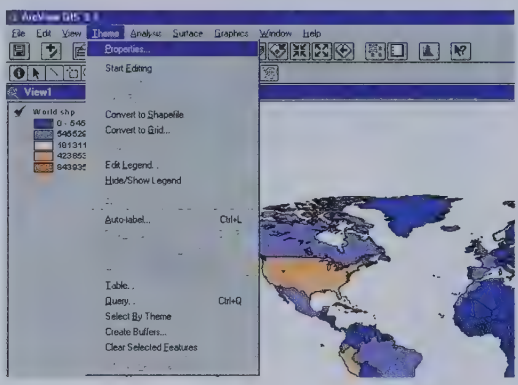
FIGURE 17.4
Sort Descending menu



The window that pops up shows the 'Attributes of the world.shp' table sorted on total fisheries production. The country with the highest production in the world is China, with a production of 47 499 759 metric tons of fish in 1999. Peru follows as second in the list with 8 439 351 metric tons. The production of China is more than 5.5 times higher than second placed Peru. This will have an effect on the way we can see differences between the countries.

What if you want to produce a map without China, so that you will get a clearer picture about the differences between the other countries? Have a try: first close the 'Attributes to world.shp' table, and go to the view of 'World.shp'. Now click on: **Theme/Properties** via the menu bar (Figure 17.5).

FIGURE 17.5
How to get to the Theme Properties window

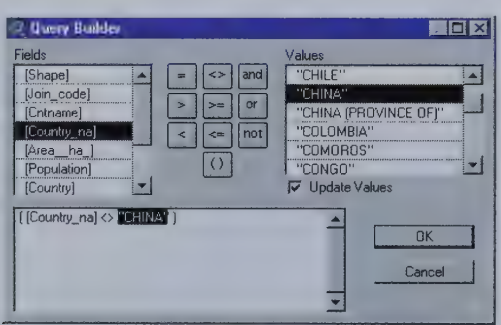


The Theme Properties window pops up. Make sure there's a square around the **Definition** Icon.

Press the **Query Builder** button.

The **Query Builder** window will pop up. Here you will be able to filter which countries are going to be shown (or will not be shown). Filter on the field **[Country_na]**, in other words: double click on **[Country_na** in the Fields select box. You will see that **[Country_na]** will appear in the bottom Query Builder box. Now select (double click) the sign <>, which means 'unequal to'. Also this will appear in the Query Builder box. The last action will be to select (double click) 'China' from the values screen (Figure 17.6).

FIGURE 17.6
A built query



Verify that the Query Builder looks the same as the above example. Now press **OK**. The Query Builder will disappear and you will see the view of 'World.shp' with the **Theme Properties** window on top of that. Press **OK** in the Theme Properties window. A new view appears, a map of the world without China (Figure 17.7).

FIGURE 17.7
View of the world without China

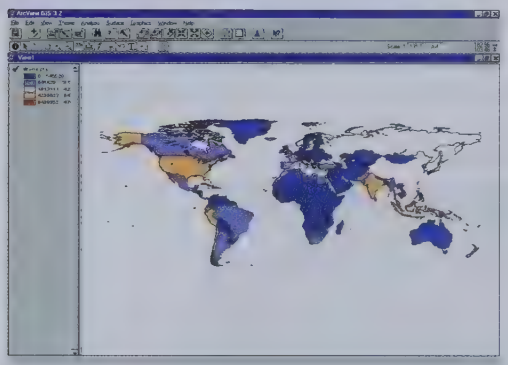
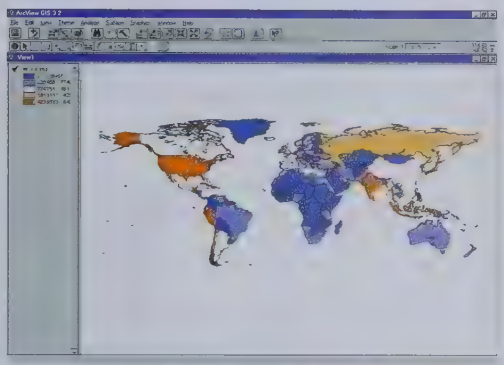


FIGURE 17.8
World fisheries production without China



The map didn't change in its legend, so there's still no clear difference between the different countries in the world. Let's change that. Go to the **Legend Editor**, change the **Classification field** to **None**, and back to **Total**. Make sure the **Color Ramps** are still on **Blues to Oranges dichromatic** and press **Apply**, close the **Legend Editor** and have a look at the result (Figure 17.8).

Now it becomes clear that after the high producer China, the other high producers are to be found in Asia and the Americas. Striking is that the countries in Africa all belong to the low producers.

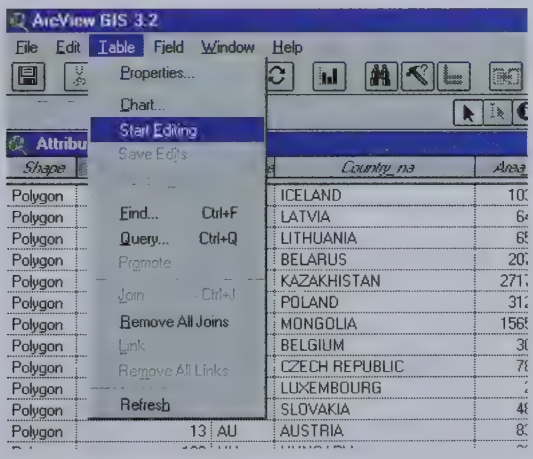
To get the complete worldmap back you simply remove the query in the Theme Properties by pressing the Query Builder button, deleting the Query, Press **OK**, again press **OK** in the Theme Properties screen, re-edit the legend in the legend editor.

Calculate

You have seen how to make a world map with the world fisheries data, clarify this map by removing the country with the highest fisheries production (China), but what about the productions per capita? If we want to see those, we first have to do some calculations which also can be done in ArcView.

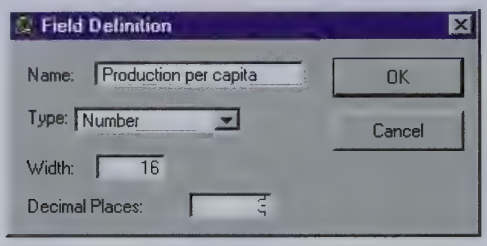
From the view of 'World.shp' go to the (new, joined) attributes of this Theme. First we have to add a field where we can put the results of our calculations. Go to: **Table/Start Editing** via the menu bar (Figure 17.9).

FIGURE 17.9
Start editing attributes table of 'World.shp'



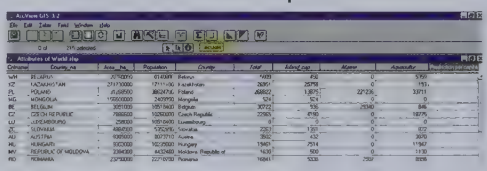
When you do that, you will see the lettertype of the field headers change from *italic* to normal (only the fields that are shown with normal lettertypes can be edited). Now we can edit the table. To add a field we go to **Edit/Add Field**. A **Field Definition** box pops up where we can define the different properties of the new field (Figure 17.10). In the **Name** field we'll put the name: 'Production per capita', **Type** field is 'Number', Width is 16, and for 'Decimal Places' we will put 3.

FIGURE 17.10
Field definition pop-up for added field



After pressing **OK** you will get a message saying: 'Field name too long. ArcView will truncate field name and use original name as alias. Continue?'. Press **Yes** and see the new field appear at the right end of the table. You can also see that the header is 'pressed' (Figure 17.11).

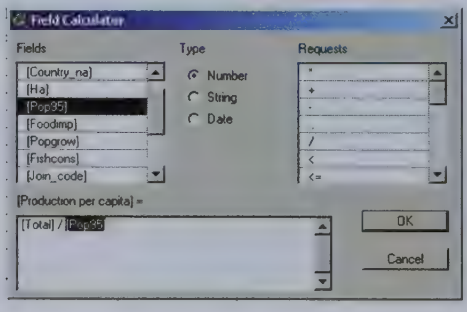
FIGURE 17.11
Attributes table of World.shp with added Field



Now the calculation can start. Make sure the header of the field **production per capita** is 'pressed'. Press the calculate button. The Field Calculator window pops up.

The field calculator has four parts; 'Fields' where you can choose with which fields you make your calculations, 'Type' which defines the fields with which you do the calculations, 'Requests' where you can define which calculations you want to make, and a field where you see the formula that you make. For the field **production per capita** we want to calculate how much fish is produced per capita in each country in kg/capita. So you have to divide the field **Total** by the field **Pop95**. First double click in the **Fields** part on **[Total]**. You will see **[Total]** appear in the bottom field. After this you go to the **Requests** part and double click a **/**. Also the slash you will see appearing in the fourth part. Now the last field we're going to put in, double click on **[Pop95]** and see it appear in the fourth part (Figure 17.12).

FIGURE 17.12
The Field calculator ready to perform the calculation



Press **OK**.

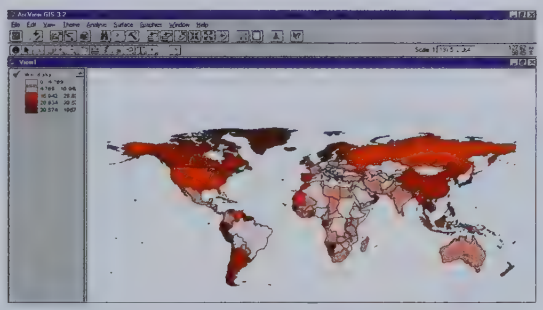
You will notice that the numbers in the **production per capita** field are very low. Why is this?

As you might have guessed we have calculated the production in metric tons per capita, while we want to get kg/capita. So we have to do the exercise again. Follow the above described procedure, after putting the **[Population]** in, also type *1000. By doing this you calculate the production per capita in kg/capita. If you now look at the attributes you will see that the figures are changed.

It is now possible to make a map with the production/capita (production per capita) figures. Go to **View** and go to the legend editor (**Theme/Edit Legend**). Change the Legend Type into Graduated color, the Classification Field into 'Production per capita' and press **Apply**.

What strikes is that China isn't among the high producers anymore, but that now Iceland, Greenland and Chile immediately show up on the map as having a high production per capita. If in the legend editor you go to **Classify** and there change the **Type** into **Equal Area**[28], press **OK** and **Apply** you will see the map change into (Figure 17.13).

FIGURE 17.13
World fisheries per capita



Try now to make maps which show Aquaculture production per capita (kg/capita), Inland Water capture fisheries production per hectare (kg/ha), and Marine capture fisheries production per country.

17.1.2 Frame survey Lake Volta, Ghana

This exercise is based on the work of de Graaf and Ofori-Danson (FAO, 1997b) in the FAO project: Integrated development of artisanal fisheries (IDAF). Lake Volta (Figure 16.14) was formed as a result of the damming of the Volta River by the Akosombo dam in 1964. The created lake has a surface area of about 8 400 km^2 or 3.6 percent of the surface area of the country, a shoreline length of 4 800 km, a maximum depth of 70 m and a mean depth of 19 m. Trees were not removed before the creation of the basin and the existing tree stumps have a considerable impact on fisheries and navigation on the lake. It was early realized that the building of the dam would have major effects apart from power production. These effects were primarily the effects on public health, transportation and the development of a new fishery.

From its creation in 1964 till 1977 fisheries was monitored thoroughly by a number of projects and Institutes. A first full frame survey, carried out in 1970 and repeated in 1975, indicated that 13 800 canoes were operated by 20 600 active fishers. The catch of Lake Volta was monitored since 1969 with a stratified catch and effort monitoring system, whereby the lake was divided in seven strata. Total catch during the period 1969–1977 is presented in Table 17.1.

[28] This method classifies polygon features by finding breakpoints so that the total area of the polygons in each class is approximately the same.

TABLE 17.1
Estimated catch of Lake Volta 1969–1977

Year	Estimated catch *(metric tonnes/year)*
1969	61 700
1970	39 200
1971	39 000
1972	36 000
1973	35 900
1974	37 300
1975	41 900
1976	40 700
1977	38 300

After 1977 the monitoring system on Lake Volta deteriorated and in 1995 major questions were:

- How many fishers are present at Lake Volta?
- What is the fisheries production?

IDAF set up, and carried out a full frame survey in Stratum 7 of Lake Volta, which lies between longitude 0° 10' west to 1° 05' west and latitude 8° 8' north to 8° 20' north and extends for about 60 km south and 50 km north of Yeji (Figure 17.14).

FIGURE 17.14
Lake Volta with stratum 7 (in red)

During the frame survey all villages were visited. In the villages interviews were held with groups of fishers. The following information was collected:

- Name of the village, when it was created and the number of ethnic groups in the village.
- Number of families, number of people per family, number of fishers per family.
- Number of canoes, number of winch boats, number of gill nets per canoe, crew number, major fishing gear, and target species.

- Transport facilities to the main market of Yeji and schooling for children.
- The number of ovens used to smoke the fish and the number of Chokor ovens.

Description of the situation in the stratum 7 of Lake Volta

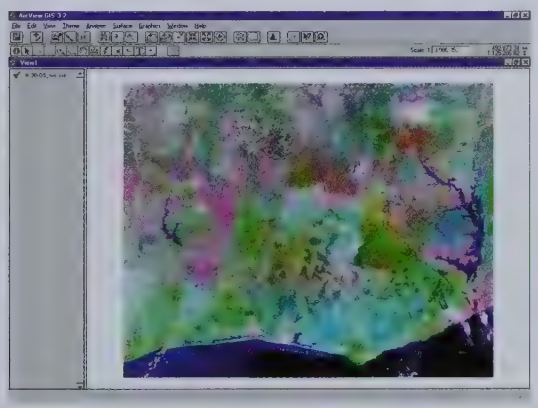
The fisheries can be characterized by the use mainly of two types of boats:

- A canoe, owned and operated by a family using gillnets, hook and line, traps, or similar equipment.
- A Winch-boat, mostly owned by large traders and operating with a hired crew of around 10 people, using a small purse seine in the deeper water.

There are almost no roads in the area and most of the transport of goods and people is done with large transport boats. Almost all fish is smoked or salted and sold once a week to large traders at the fish market of Yeji. Most of the fish is smoked in traditional ovens which use a considerable quantity of wood. Deforestation of the shorelines is a major problem and risk for Lake Volta. Therefore the project introduced the use of the Chokor oven which uses less fuel wood. All data are digitized and can be used to carry out a preliminary analysis in GIS in the following exercise.

1. Open ArcView, Open a New Project, and Open a New View. Set the working directory. Make sure the extension MrSid Image Support is installed (go via the menu bar to: **File/Extensions...**, and check the box of MrSid Image Support). This extension makes it possible to work with satellite images.
2. Add the Theme 'N-30-05_loc.sid' from the 'RW_02_Lake_Volta' folder to the View. Make sure you have 'Image Data Source' in the Data Source Types: selection box. Check the legend checkbox of the Theme, and wait a while, as this is a very big file. After waiting you will see Figure 17.15. This is a picture of west Central Africa, and if you look on the right hand side, you will see Lake Volta. Compare this picture with Figure 17.14.

FIGURE 17.15
After loading the 'N-30-05_loc.sid' Theme



You are now requested to make an analysis of the situation in Stratum 7 of Lake Volta, the part where the IDAF project was situated. This analysis should include:

- An ArcView-project with which people can get an impression with photographs of the fisheries in Lake Volta.
- A Theme indicating the canoe, winch boat distribution over the villages, where also the number of fishers per village is indicated.
- A Theme (or several maps) showing socio-economic data (like average family size per village, the number of fishers per family per village, villages with chokor ovens).
- A Theme (or several maps) showing fisheries data (like distribution of gillnets and beach seines over the villages, indicating which villages target Tilapia, or

Chriysichtys, average number of crew per canoe over the villages, the number of gillnets per canoe over the villages).

- A Theme which shows the position of the Akosombo dam downstream of Lake Volta.

For this you have the following data available in the 'RW_02_Lake Volta' folder:

N-30-05_loc.sid: The satellite image you have opened before of Central west Africa, with Lake Volta on the right-hand side.

DATA_FRAME_SURVEY.xls[29]: The file containing the data of the frame survey done by the IDAF project. For a description of the data, see the description of the frame survey on the previous page.

Stratum 7.shp: The Stratum 7, The area of the IDAF project.

Chokor.bmp: A photograph showing the Chokor oven, a fuelefficient oven to smoke fish.

Shoreline.bmp: A photograph showing the shoreline of Lake Volta. Pay special attention to the bare trees on the wateredge.

Brush park.bmp: A photograph showing the nifa nifa system. This system is specific for Lake Volta to catch Tilapia. At night the nets are lowered, after which the Tilapia gets stuck in the net, and can get harvested.

Yeji Market.bmp: The place where fish is being sold.

Landing catch.bmp: Close to Yeji market the fish is being landed, do you see the fisheries officer of IDAF collecting the data?

Photo location.shp: A point Theme showing the locations where the above three pictures were taken.

Roads.shp: The roads close to the Stratum 7 area.

---

[29] The following abbreviations are used as field names in the different Themes:

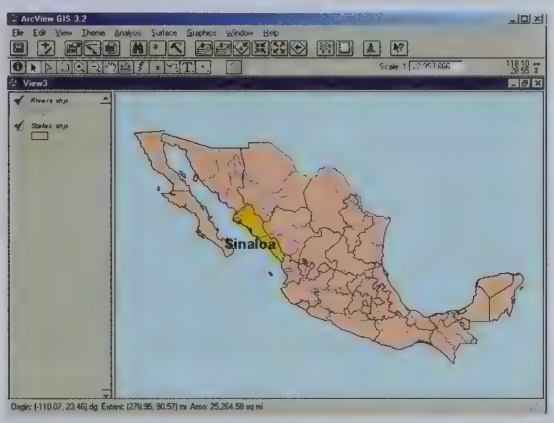
Ethnic	Number of ethnic groups in the village
Population	Total population in the village
Year	Year of construction of the village (0 = unknown)
Nhh	Number of households
Avppphh	Average number of persons per household
Avgfphh	Average number of fishers per household
Fishers	Total number of fishers in the village
School	Presence of school
Canoes	Number of canoes
Bundles	Average number of gillnets used per fishers
Crew	Number of crew per canoe
Winch	Number of winch boats operating from the village
Species	Major species in the catch (TI=Tilapia, HS=Hemisynodontis/Synodontis, CH=Chrysichthys)
Gear	Major gear used (GN=gill net, TR=traps, W=winch, BS=Beach seine)
Avgoven	Average number of fish smoking ovens
Totoven	Total number of ovens
Chokor	Number of Chokor ovens, ovens which use less fuel wood and which were promoted by the project
Transpboat	Transport boats available in the village

17.1.3 GIS analysis of catch data of artisanal fisheries in Sinaloa, Mexico

Sinaloa (Figure 17.16) is one of Mexico's major fishing states. It ranks first in terms of commercial value of output and fourth place in terms of volume of the catch. The shrimp catch, which accounted for more than one third the national total in the past five years, is of prime importance.

The state's fishing industry is primarily a supplier of fresh products. Approximately 95 percent of output is for direct human consumption, and the remaining 5 percent is processed in 119 plants. Spectacular growth has been seen in Sinaloa's aquaculture in recent years. In 1987 there were only 27 fish or shirmp farms, in 1995, that number had climbed to 138. In the same period output of shrimp farms rose from 585 metric tons to 8 725 metric tons.

FIGURE 17.16
Sinaloa state



The artisanal marine catch of Sinaloa is recorded by 10 fisheries offices and data recorded over the period 1990–1999 can be analysed with GIS[30]. The major objective of this exercise is to show linking of data which is not covered in the first part of the manual.

To complete the exercise you will have to perform the following tasks:

- Map the office locations onto a base map of Sinaloa State.
- Link a data table of catch statistics to the map of office locations.
- Create a map showing the average catch of selected species per office.

To complete the task, you will need to use the following ArcView Themes and data tables:

- 'Sinaloa.shp' (map of Sinaloa).
- 'Water.shp' (map of all water features (lakes, rivers etc.) in Sinaloa).
- 'Fisheries Offices.shp' (map of fisheries offices and their location).
- 'Catches.dbf' (data table of catch statistics).

1. Open ArcView, New project, new View.
2. Add the Themes 'Sinaloa.shp', 'water.shp' and 'fisheries offices.shp' from the 'RW_Mexico' folder.
3. Close the new View and Add the table 'Catches.dbf' from the 'RW_Mexico' folder.
4. Open the 'catches.dbf' table and you will see that it contains 23 fields:

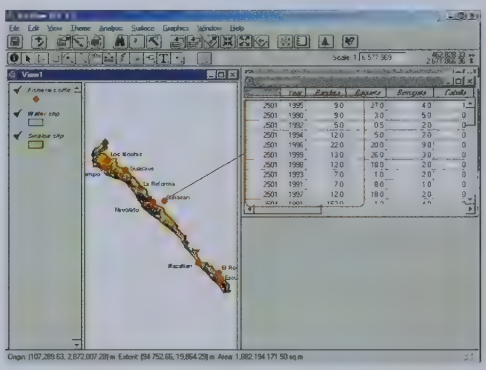
- **Ofcode** – a code assigned to each office;
- **Year** – year when catch data was recorded;

[30] The original exercise was made by Paul Eastwood, Fisheries GIS Unit, Department of Geography, Canterbury Christ Church University College, UK, with data provided by Arturo Ruiz, but is slightly adapted for this manual.

- **Bandera, Banqueta...Tiburon** – catches (in tonnes) of fish per species, the Scientific and English common names are provided in Table 17.2;
- **Total** – total catch (in tonnes) of all species.

The first step would be to join the fisheries data in the table with the location of the fisheries offices and this can be done by using the 'Ofcode' in both themes. However, if you do this the way explained in the chapter: Joining data with location on a map on page 22, you will see that not all data of the catch table will be joined with the attribute table of the fisheries offices. The problem is that the Catch data table contains more then one row (= a record) of data, one row for each year, for each office location (Figure 17.17).

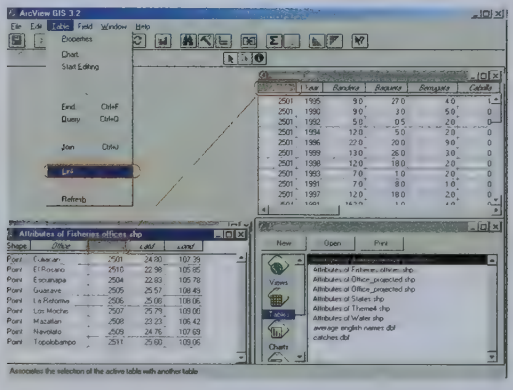
FIGURE 17.17
Multiple data per fisheries office



This is what in GIS is called a 'One-to-Many' relationship. If you join the 'catches.dbf' table with the 'fisheries offices.shp' Theme, ArcView will take the first related record from the table, and ignore the additional records for each office. In these cases, you should **link** the tables instead.

5. Open the 'catches.dbf' table, tile the window, open the 'attribute of fisheries offices.shp' table, tile the window. Activate in both tables the field name 'ofcode'. To link the two tables, from the Table menu choose **Link** (Figure 17.18).

FIGURE 17.18
Linking two tables



If you look at the 'Attribute of Fisheries offices.shp' table you will see that nothing has changed after this action. But the two tables are linked which you can see with the select feature tool:

6. Make the View window active and use the select feature tool to select any of the offices, i.e. by clicking on the office locations in the view window. All

linked records in the catches.dbf table will be selected (selected records are highlighted in yellow). Once an office and its associated records in the 'catches.dbf' table have been selected, they can be grouped together into a single block.

To do this, first make the 'catches.dbf' table active, and then click the promote records button . This moves all highlighted records to the top of the data table.

Statistics for the selected records are obtained by first clicking on a column header in the 'catches.dbf' table, then from the Field menu choose Statistics (**Field/Statistics...**) (Figure 17.19 and Figure 17.20). If no records are selected then statistics will be given for all records in the chosen column.

FIGURE 17.19
How to get statistics on selected records

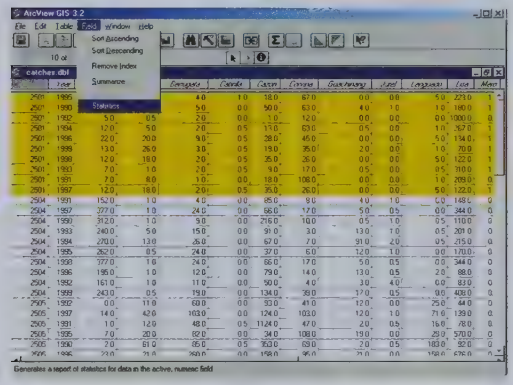
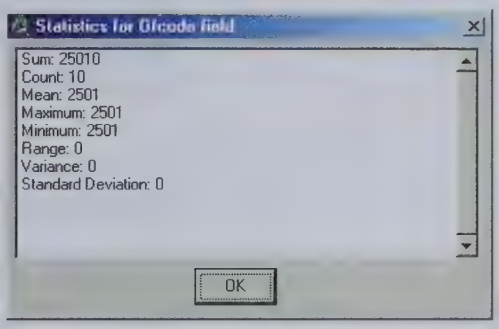


FIGURE 17.20
The statistics window



Please answer the following questions by selecting offices from either the table or the map and examining the associated catch data:

7. Find the mean catch of Berrugata recorded at the Los Mochis office for the years 1990 to 1999.
8. For the Mazatlan office, find the maximum recorded catch of Tiburon and the year when it was recorded.
9. Find the total recorded catch of all species at the Topolobampo office for the entire ten year period.
10. Which office recorded the highest catch of Lenguado in 1995, La Reforma or Guasave?
11. Lisa (*Mugil cephalus*) is the most common species caught by artisanal fishers in the coastal waters of Sinaloa. (You will need to examine the statistics of each office in turn to answer some of these questions).
12. Which office recorded the highest mean catch of Lisa over the entire ten year period?
13. How many offices recorded a mean catch of over 100 tonnes?
14. Is there a spatial pattern in the distribution of catches, e.g. high catches in the north, low catches in the south?

You may have noticed that some species are caught in greater abundance than others. The top three species or species groupings in terms of mean catches over the ten year period are:

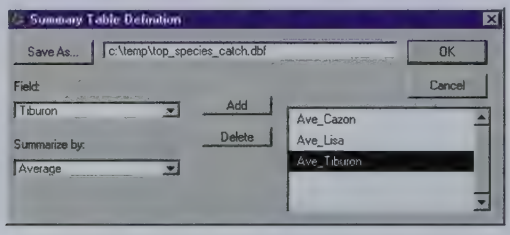
- Lisa, *Mugil cephalus.*
- Cazon, juveniles of several shark species.
- Tiburon, *Carcharhinus* spp.

The data for Lisa, Cazon and Tiburon will now be extracted from the catches data table and examined in more detail.

15. Make the 'catches.dbf' data table active and click on the column header labelled 'Ofcode'. From the **Field** menu choose **Summarise....** In the Summary Table

Definition dialogue box that appears, select 'Cazon' from the Field: pull-down menu and 'Average' from the Summarize by: pull-down menu. Click **Add**. Repeat the procedure for Lisa and Tiburon. Click **Save As**, navigate to a folder where you can save the file and enter an appropriate file name. The Summary Table Definition dialogue box should something like this:

FIGURE 17.21
Summary Table Definition



16. Click **OK** to create the summary table file.

The summary table can now be joined to the 'Fisheries offices.shp' Theme. Click on the 'Ofcode' column header in the summary table and then the 'Ofcode' column header in the 'Attributes of Fisheries offices.shp' table. From the **Table** menu choose **Join**. The summary table should now be joined to the 'Attributes of Fisheries offices.shp' table.

The table contains unnecessary data and can be tidied up. Make the 'Attributes of Fisheries offices.shp' table active. From the **Table** menu choose **Properties...**. In the Table Properties dialogue box make sure that a tick only appears alongside the 'Office', 'Ave_Cazon', 'Ave_Lisa', and 'Ave_Tiburon' fields by clicking in the 'Visible' column to remove ticks from unwanted fields. In the 'Alias' column, type 'Cazon' alongside the 'Ave_Cazon' field, 'Lisa' alongside the 'Ave_Lisa' field and 'Tiburon' alongside the 'Ave_Tiburon' field (Figure 17.22).

FIGURE 17.22
Cleaning up a table

Visible	Field	Alias
	Shape	
✓	Office	
	Ofcode	
	Latd	
	Lond	
	Ofcode	
	Count	
✓	Ave_Cazon	Cazon
✓	Ave_Lisa	Lisa
✓	Ave_Tiburon	Tiburon

17. Click **OK** to save the changes to the table properties.

In the 'Attributes of Fisheries offices.shp' table increase the width of the columns so that all of the data and column headers are clearly visible. The table should now look like Figure 17.23.

FIGURE 17.23
The Attributes of office locations

Attributes of Office locations.shp

Office	Cazon	Lisa	Tiburon
Culiacan	22.6000	263.7000	7.0000
El Rosario	14.9000	33.4000	2.6000
Escuinapa	89.1000	211.1000	40.7000
Guasave	228.6000	269.3000	46.2000
La Reforma	115.7000	159.6000	34.8500
Los Mochis	39.5000	53.9000	26.1000
Mazatlan	543.4000	115.0000	690.6000
Navolato	112.7000	81.2000	31.6000
Topolobampo	29.8000	143.4500	225.8000

The data for 'Lisa', 'Cazon' and 'Tiburon' can now be plotted on the map of office locations (Figure 17.24).

FIGURE 17.24
The data of different fish species per fisheries office

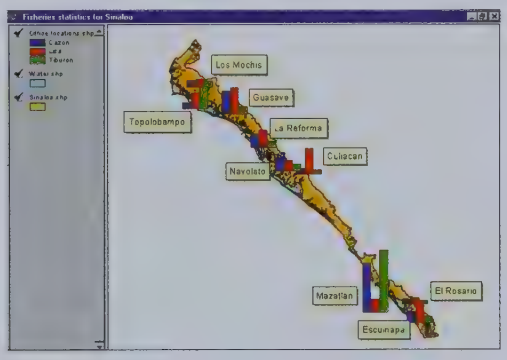


TABLE 17.2
Spanish, Scientific and English fish species names

Spanish name	Scientific name	English Name
Bandera	*Bagre Panamensis*	Chilhuil sea catfish
Baqueta	*Epinephelus acanthistus*	Rooster hind
Berrugata	*Menticirrhus panamensis*	Panama king kroaker
Cabrilla	*Myctoperca rosacea*	Leopard grouper
Cazon	*Nasolamia velox*	Whitenose shark
Corvina	*Cynoscion nebulosus*	Spotted weakfish
Guachinango	*Lutjanus spp*	Snapper
Jurel	*Caranx latus agassiz*	Horse-eye jack
Lenguado	*Hippoglossina tetropthalma*	Fourspot flounder
Lisa	*Mugil cephalus*	Flathead mullet
Mero	*Enicephalus itajara*	Itajara
Pampano	*Trachinotus carolinus*	Florida pompano
Pargo	*Lutjanus argentiventris*	Yellow snapper
Pierna	*Caulolatilus princeps*	Ocean whitefish
Rayas	NA	NA
Robalo	*Centropomus undecimalis*	Common snook
Ronco	*Pomadasys panamensis*	Panama grunt
Rubia	*Lutjanus inermis*	Golden snapper
Sierra	*Scomberomorus sierra*	Pacific sierra
Tiburon	*Echeneis naucrates*	Live shark sucker

17.1.4 Floodplain fisheries monitoring and GIS, an example from Bangladesh

Fisheries in Bangladesh[31]

Fish plays an important role in the daily life of many people in Bangladesh, as it is a country of rivers and floodplains, with a high potential of aquatic resources. The Bengali expression 'Mache bhate Bengali', or 'Fish and rice make a Bengali', expresses this importance. Bangladesh produces 1 500 000 tonnes of fish annually (FAO, 2000). Inland capture fisheries and aquaculture are the main contributors to this production. About 12 millions people depend on fisheries, of which 1.2 millions are fulltime dependent on fish and fishing activities (de Graaf *et al.*, 2001).

Fish production in Bangladesh, as in other floodplain areas in the world, cannot be properly considered without knowing the specific characteristics. Reproduction and growth of fish and prawn in Bangladesh are strongly related to the sequence of flooding (Junk, Bayley and Sparks, 1989). The floodplains, which are inundated during the monsoon season, are nutrient and food rich and play a significant role for 4–5 months of the year. Larvae, juveniles and adults grow in this habitat, after which they migrate back to rivers or depressions at the end of the monsoon, when waters recede. In this period the fish are more vulnerable to fishing.

Habitat stratified fisheries monitoring

Inland fisheries are traditionally monitored through so-called catch and effort monitoring systems. Where effort (F) is the number of fishers, or the number of gears, operated in a waterbody, and catch (CPUE) is the daily catch harvested per fisherman, or gear. The total catch (C) is obtained by multiplying the catch per fishers (or gear) (CPUE) with the total number of fishers (or gears) (F). A prerequisite for a catch and effort monitoring system is that the total effort (F, the total number of fishers (or gears) operated) is known.

This would mean for floodplain fisheries monitoring that an incredibly large number of households would have to be followed throughout the year, because most of the catch is not landed centrally, but is taken home and consumed (as for instance 60–70 percent of the rural population on the floodplains of Bangladesh is engaged in 'subsistence fishing[32]). This large household survey would be very costly, making a traditional catch and effort monitoring system not an attractive option.

The Compartmentalization Pilot Project (CPP), a water management project in Bangladesh (Figure 17.25), developed a more practical monitoring system over the period 1992–2000. This habitat fisheries monitoring programme was based on traditional catch and effort data recording, and was combined with hydrological modelling developments[33], resulting in a final analysis in a GIS environment.

[31] The exercise is based on work of de Graaf, Born, Uddin, and Marttin (2001) in the Compartmentalization Pilot Project implemented from 1991 – 2001 in Tangail, Bangladesh.
[32] Fishing for their daily consumption.
[33] Spatial and temporal.

FIGURE 17.25
The CPP project in Bangladesh

Basic principles of habitat stratified floodplain fisheries monitoring

The principle of the fisheries monitoring programme developed by CPP is a stratification of catch and effort monitoring. Stratification means that the area to be monitored is divided into different habitat-types. Of each different habitat type a small part was selected, becoming a representation for the habitat type. These standard sites were monitored closely with a normal catch and effort monitoring programme. The results of these small monitoring programmes were extrapolated, per habitat type, over the whole project area.

The estimation of the total catch followed three steps:

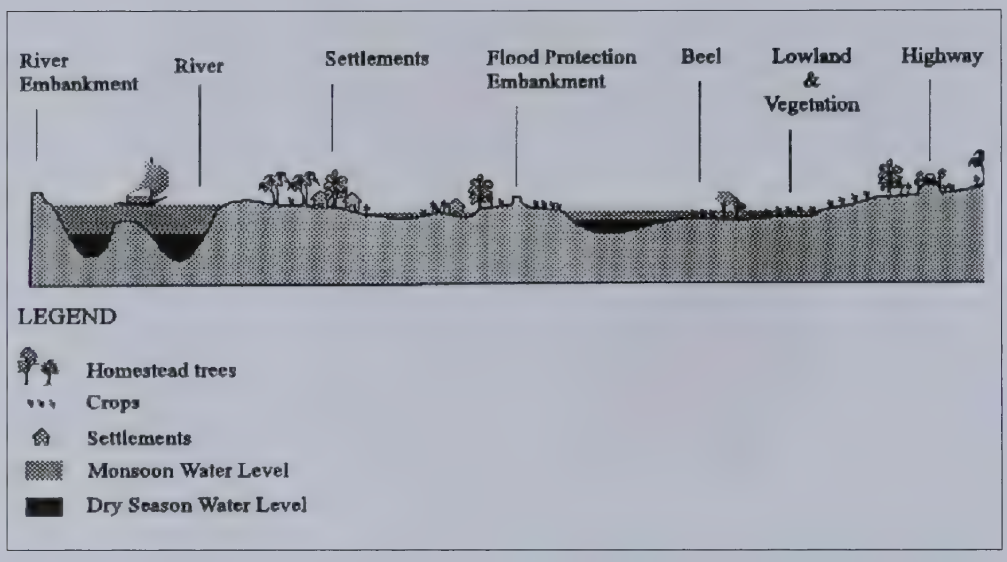
- The Catch per Unit of Area (CPUA) for each type of habitat was determined as accurately as possible with traditional catch and effort monitoring.
- The total flooded area (A) for each type of waterbody (or habitat type) was determined as accurately as possible with GIS.
- The total catch per type of waterbody (or habitat type) was determined by multiplying the catch per unit of area with the actual area. (CPUA * A = total catch).

Stratification of the CPP area, or criteria and principles

The waterbodies/habitat types (Figure 17.25) in the floodplains of Bangladesh can be classified as:

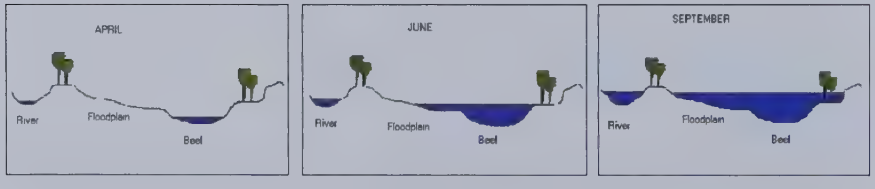
- **Beels**: These are the low-lying depressions in the floodplain (small lakes). They may have a permanent character, containing water throughout the year (permanent waterbodies) or dry out completely in the dry season, usually for a period of 4–5 months (seasonal waterbodies).
- **Floodplains**: Land inundated during the monsoon because of rainwater congestion and river flooding.
- **Rivers and canals**.

FIGURE 17.26
Cross-section of a typical floodplain system in Bangladesh



Classification and selection of rivers and canals is straightforward, but the classification and selection of beels and floodplains is more complicated, as they are hydrologically linked and very dynamic. The following figure shows this extremely dynamic character, where the floodlevels and the inundated area of the floodplain in the CPP area during the months April, June and September are presented.

FIGURE 17.27
Water level and inundated area of a floodplain system at three moments during the year



In April, there is no inundated floodplain, and the average water depth in the beel, which covers an area of 100 ha, is 1 metre.

Two months later, in June, there is on average 0.3 metres of water in the floodplain, which at this time covers an area of 1 200 ha, while the average water depth in the beel has increased to 2 metres and the beel covers an area of 150 ha.

Another two months later, in September, there is on average 0.3–1.5 metres of water in the floodplain, depending on where you are, and an area of 2 000 ha of floodplain is inundated.

The time intervals in this illustration are quite big (two months), but even within one month during the flood season water levels may vary significantly. This phenomenon makes it difficult to use water levels as selection criteria for habitat fisheries monitoring, as it would mean that these habitats would not be fixed in one place. This was the reason why the fisheries team of the CPP project looked for other criteria to classify habitats. These criteria needed to be quantifiable, replicable, usable all over Bangladesh, and practical.

In Bangladesh all land is classified (by the Master Planning Organization, MPO) for suitability of agriculture practices. This MPO classification is well known by large groups of planners, scientists, departments, farmers, and could be described as a flooding risk classification of land. After careful consideration it was concluded that this system could be used for the habitat fisheries monitoring programme in the CPP project. The MPO classification classifies land according to the risk of flooding for three consecutive days with a certain maximum water level. This risk of flooding determines which type of crops can be grown during the monsoon season. The different classes with their criteria are in Table 17.3, you see that fishing is carried out mainly in the F3 and the F2 lands.

TABLE 17.3
Land classification according to the Master Planning Organization, Bangladesh

Maximum flooding depth for three days *(cm)*	Landtype	Risk of flooding	Land use during the monsoon
0–30	F0	Very low risk of flooding	sugarcane, vegetables, rice
30–90	F1	Low risk of flooding	rice
90–180	F2	High risk of flooding	rice, floating rice, fish
>180	F3	Certainly flooded	floating rice, fish

The landtypes in a certain area only change if the water management in that area is changed. This happened for instance with the CPP area. Before the 1970s, the CPP area was more or less an unprotected floodplain. Large areas were flooded annually, and large areas were classified as F3 and F2. An embankment around the area was built in the 1970s, which highly reduced the risk of flooding, resulting in a reclassification of a large area of land previously classified as F3/F2 into F2/F1.

The developers of the habitat-stratified floodplain fisheries monitoring programme assumed that data obtained from a landtype site was representative for the total flooded area of this landtype, irrespective of the actual water level measured at that site. For instance, if the catch in 10 ha of flooded F3 land was well monitored during a certain period, it was considered representative for the total area of flooded F3 land during this period. This assumption allowed concentrating on the fixed sites within the project area. As a result a sound analysis was possible, considering even the limited amount of resources.

The monitoring programme

The goal of the stratified monitoring programme was to estimate the monthly CPUA of the different habitat types (in this exercise the different landtypes, F2 and F3), and to estimate monthly what the flooded area was of the different habitat types (F2 and F3). With these figures it was possible to estimate the monthly catch per

habitat type ($CPUA_{Fx}$ * $Area_{Fx}$ = Catch of the habitat type Fx). Adding the results of the different habitat types resulted in the total catch from the floodplains of the project area ($Catch_{F2}$ + $Catch_{F3}$ = Total catch).

To be able to establish the monthly CPUA per landtype (F2 and F3) several sites were selected that were representative for all other sites with the same landtype. The area of these sites was measured accurately, so that after establishing the monthly catch per site, the monthly CPUA per landtype was easy to establish ([Monthly catch]/[Area] = CPUA).

Two surveys were done at the selected sites:

- **Catch assessment survey:** provided information on the average monthly catch per fishers (CPUE) at a selected site. The daily catch of every individual fisherman was monitored regularly at each site. The numbers and weight of the dominant species in the catch were recorded. Furthermore, the gear-type, its mesh size, owner status and the number of units used per fisherman were recorded.
- **Frame survey**: provided information on the average number of fishers (F) operating at a selected site. It consisted of regular standardized counting of the number of fishers, and gears used.

From these two surveys the average monthly catch could be established per site (CPUE * F = Catch), after which the CPUA of the landtype the site represented could be established ([Catch] / [Area] = $CPUA_{Fx}$).

Using GIS, the total inundated area per landtype was determined, after which it was possible to estimate the total catch ([$CPUA_{F2}$ * $Area_{F2}$] + [$CPUA_{F3}$ * $Area_{F3}$] = Total Catch).

Figure 17.28 shows the sites which were monitored for eight years in the CPP area. Data from the sampled sites you can find in Table 17.4 and Table 17.5.

FIGURE 17.28
Sampling sites of the fisheries monitoring programme in the CPP project area

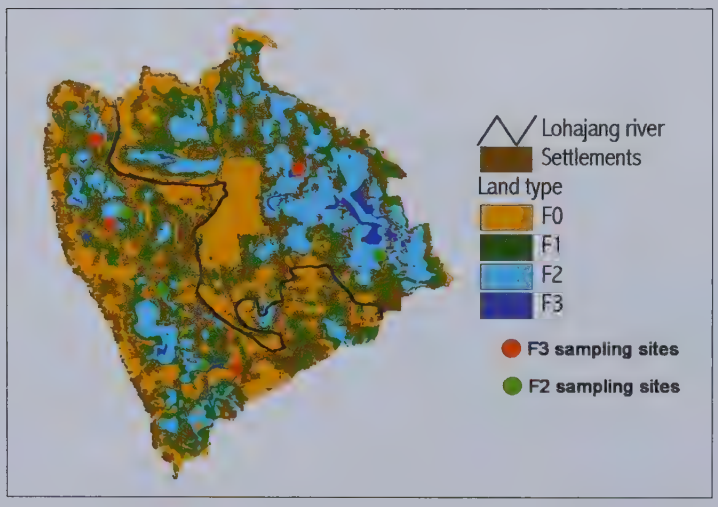


TABLE 17.4
Fisheries data (1997) from F3 sampling sites

Month	Number fishers per day (F)	Catch per fishers per day (CPUE) (kg/day)	Daily Yield in sampled Area (CPUE * F = Catch) (kg/day)	Monthly yield (Catch*days) (kg/month)	Sampled Area (ha)	CPUA (Catch/Area) (kg/ha/month)
January	3	0.68	2.04	63.24	4.22	14.99
February	3	1.07	3.21	89.88	3.60	24.75
March	3	0.87	2.61	80.91	3.77	21.46
April	3	1.06	3.18	95.40	7.19	13.27
May	6	1.13	6.78	210.18	8.90	23.62
June	6	1.41	8.46	253.80	10.01	25.35
July	8	0.63	5.04	156.24	17.10	9.14
August	5	0.75	3.75	116.25	17.80	6.53
September	11	1.28	14.08	422.40	17.80	23.73
October	15	3.06	45.90	1 422.90	12.23	116.35
November	8	0.96	7.68	230.40	6.52	35.34
December	4	0.91	3.64	112.84	5.63	20.04

TABLE 17.5
Fisheries data (1997) from F2 sampling sites

Month	Number fishers per day (F)	Catch per fishers per day (CPUE) (kg/day)	Daily Yield in sampled Area (CPUE * F = Catch) (kg/day)	Monthly yield (Catch*days) (kg/month)	Sampled Area Area (ha)	CPUA (Catch/Area) (kg/ha/month)
January	9	0.74	6.66	206.46	11	18.77
February	0	0.00	0	0	11	0
March	0	0.00	0	0	11	0
April	0	0.00	0	0	11	0
May	0	0.00	0	0	11	0
June	0	0.00	0	0	11	0
July	5	0.56	3	86.80	11	7.89
August	15	0.72	11	334.80	11	30.44
September	13	1.25	16	487.50	11	44.32
October	9	2.57	23	717.03	11	65.18
November	15	0.85	13	382.50	11	34.77
December	3	1.50	5	139.50	11	12.68

The data show that floodplain fisheries in the project area are highly seasonal with peak yields in October (Figure 17.29). This strong seasonality makes it essential that analysis of data and estimation of total catch is carried out on a monthly basis.

FIGURE 17.29
Seasonal variation in fishing effort and CPUE in the floodplain (F3) of Bangladesh

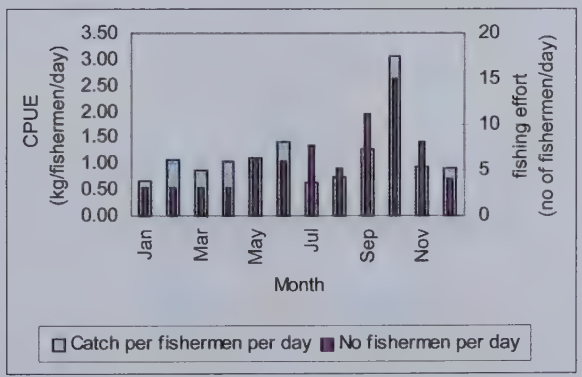


Table 17.4 and Table 17.5 show monthly Catch per Unit of Area (CPUA) for F3 and F2 landtypes, respectively. To calculate the total catch from these landtypes in the project area, you need to know the flooded areas of these landtypes in the project area. When you have these, the total monthly catch in the floodplains of the project area can be calculated by filling in Table 17.6.

TABLE 17.6
Frame for the estimation of the monthly floodplain catch in the CPP project

Month	$CPUA_{F3}$	Area $_{F3}$ flooded	Total Catch $_{F3}$ $CPUA_{F3}$*Area $_{F3}$ flooded	$CPUA_{F2}$	Area $_{F2}$ flooded	Total catch $_{F2}$ $CPUA_{F2}$*Area $_{F2}$ flooded
January	14.99			18.77		
February	24.75			0	0	0
March	21.46			0	0	0
April	13.27			0	0	0
May	23.62			0	0	0
June	25.35			0	0	0
July	9.14			7.89		
August	6.53			30.44		
September	23.73			44.32		
October	116.35			65.18		
November	35.34			34.77		
December	20.04			12.68		

Determination of monthly inundated areas or monthly flood maps

Previously you made a flood map of Pais Pesca through interpolation of measured water levels, calculation of the water level by subtracting the generated grid from the available topographic level and finally you made the flood map by reclassifying the dry and flooded areas. This method was used to make floodmaps of the CPP area.

Next to fisheries data, water levels were measured weekly in a large number of sites throughout the project area. These waterlevels were used in a hydrological model to make a waterlevel map. A reliable topographic map or a Digital Elevation Model (DEM) was subtracted from this water level map to make monthly flood maps. Open the presentation (by double clicking the file in MS Explorer) 'flood maps 92–99.pps' in the 'RW_03_Floodplain' folder on the CD. Let it run and pay attention specifically to the change in water levels during the years (blue is water, yellow is land) to get an idea of the extend and the seasonality of flooding in the CPP project area.

Land in the CPP area was classified according to the MPO classifications (see Table 16.3 for the criteria) With the flood maps and the landtype map you can calculate the monthly flooded area per landtype by querying (Figure 17.30) the two with the criteria:

- Give all areas with water in the flood map grid and which are F3 in the Landtype grid; and
- Give all areas with water in the flood map grid and which are F2 in the Landtype grid.

All steps for the analysis to arrive at the monthly flooded areas of the different habitats are summarized in Figure 17.31.

FIGURE 17.30
The principle of querying the floodmap with the landtype map

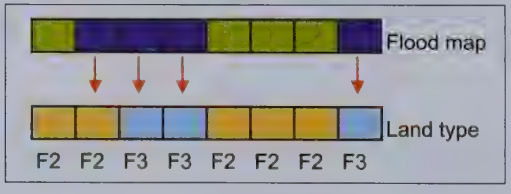
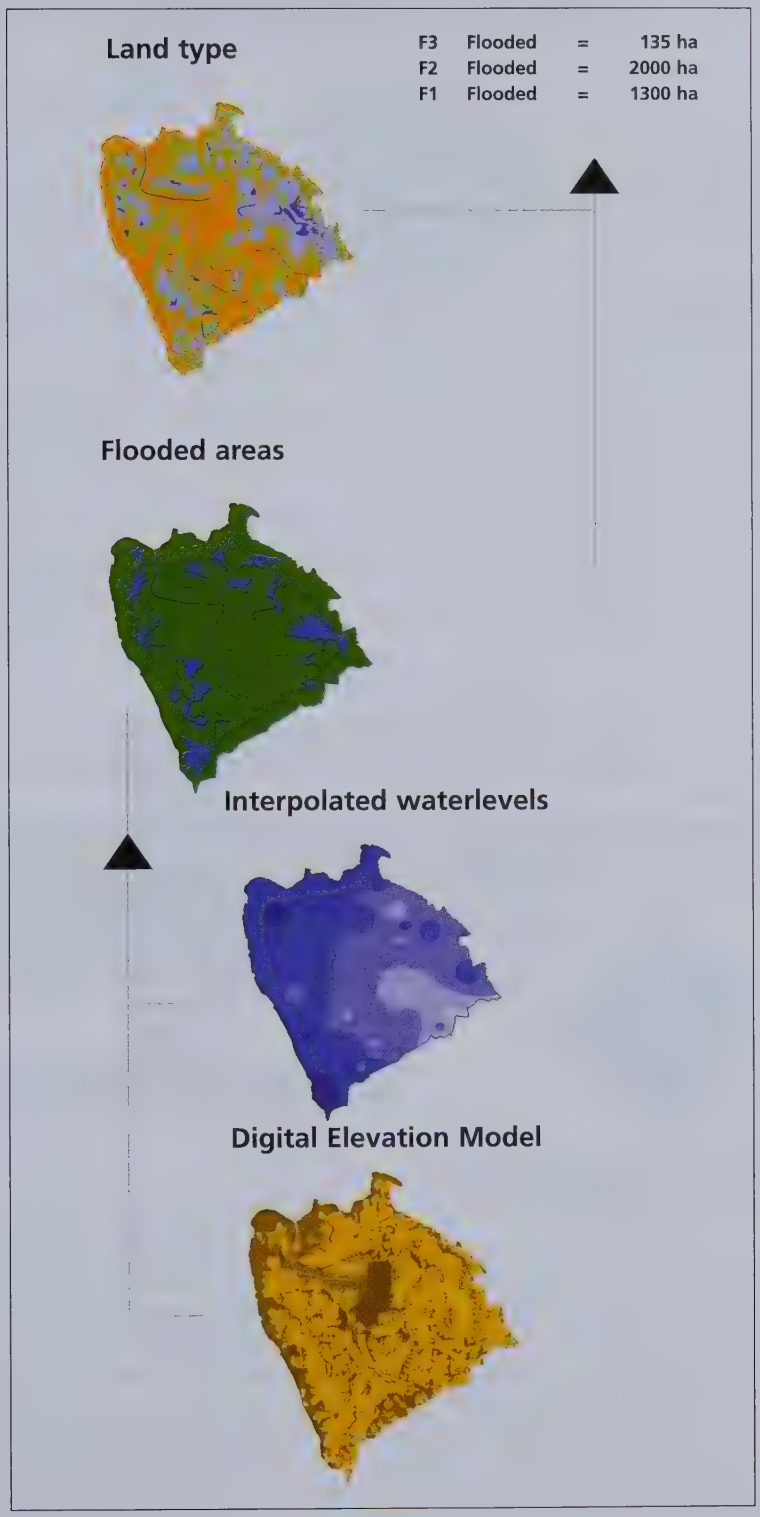


FIGURE 17.31
Pathway of determination of monthly flooded area per habitat in the CPP project area



Estimation of floodplain fish catch in the CPP project area

The objective of this exercise is to estimate the annual catch in the floodplains of the CPP project area. For this you will calculate with GIS the missing data in Table 17.6 on page 114.

Making floodmaps

This exercise is similar to the exercise starting on page 70. You will have to make floodmaps of the CPP area showing dry and flooded land.

1. Start ArcView, New project, New View. Add from the folder rw_03_floodplain from CD2 the Feature Data Source Themes 'Bangladesh.shp', 'CPP_outline.shp', 'Waterlevels.shp', and the Grid Data Source Theme 'Topography' to the View. Make sure to load the legend of 'Topography'.
2. Set the working directory to a directory of your choice (for instance D:\Bangladesh\temp\). Do not set the projection, but set the map units and distance units to meters.
3. Make a mask for the analysis from the 'CPP_outline.shp' Theme by converting it into a grid (menu bar: **Theme/Convert to Grid...**) (Output Grid Extent: Same As Display, Cell size: 10 metres).
4. Set the 'CPP_outline' grid Theme as a mask (menu bar: **Analysis/Properties...**)

Now you are ready to do a complete analysis, but for this exercise you will only do the month of January.

5. Interpolate the waterlevels for the month January (**Surface/Interpolate Grid...**, Output Grid Extent: Same as Display, Cell Size: 10 metres, Method: IDW, Z Value field: January). You can get the same legend as in Figure 17.32 by loading the legend: **Theme/Edit Legend,** press **Load**, locate the file 'waterlevels.avl' in the RW_03_floodplain directory.

FIGURE 17.32
Interpolated waterlevels for January in the CPP project

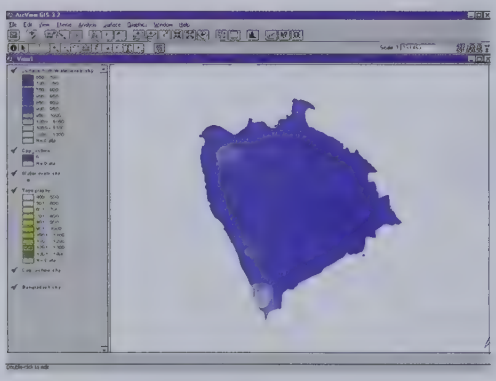
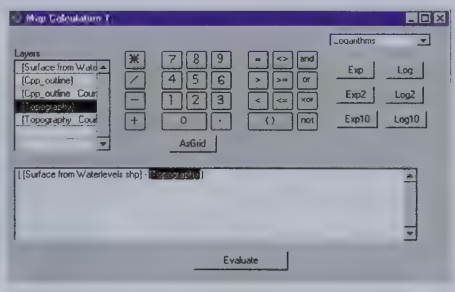


FIGURE 17.33
Calculating the waterdepth

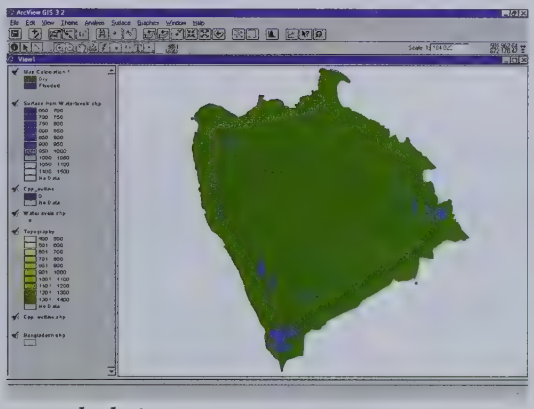


6. Calculate the water depth using the map calculator, calculating Water depth = Surface from Waterlevel.shp - Topography (Figure 17.33).

Make a flood map of the project area in January, showing dry and flooded land (negative values are dry land, positive values are flooded) by reclassifying the calculated grid, either via reclassifying the analysis (menu bar: **Analysis/Reclassify...**), or via the legend editor (**Theme/Edit Legend...**).

If you did everything correct you have made the grids as presented in Figure 17.34.

FIGURE 17.34
Calculated water depth for January in the CPP project area

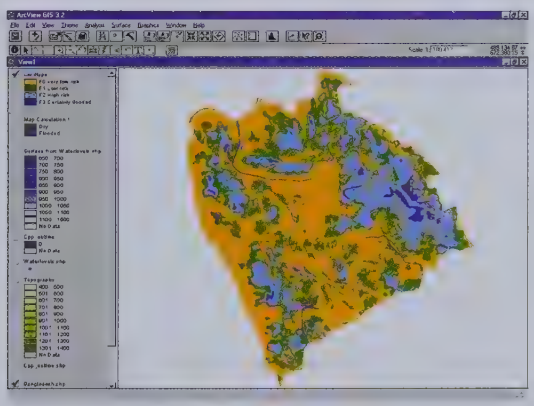


Monthly flooded area calculation

You need to calculate the monthly flooded areas of the different landtypes (F2 and F3) in the project area. This can be done by querying the flood maps with the landtype map.

7. Add the Theme 'Landtype' (from the folder 'RW_03_floodplain' on the CD) to the View. Load via the Legend editor (menu bar: **Theme/Edit Legend...**) the Legend 'Landtype.avl' from the RW_03_floodplain folder on the CD (Figure 17.35).

FIGURE 17.35
Landtypes in the CPP project area



This landtype Theme you have to query with the monthly flood maps. You just made the flood map for the month January. the floodmaps for the other months are already made and are called 'DWJAN' for January, 'DWFEB' for February, 'DWMAR' for March, 'DWAPR' for April, etc.

8. Add the flood map for January ('DWJAN') to the View.

9. Query the 'Landtype' with the flood map of January ('DWJAN') for F3 Landtype (via **Analysis/Map Query...**, Figure 17.36). Open the Theme Table of 'Map Query 1' and you will see that there are 25 286 pixels fitting the criteria 'F3 landtype' and 'flooded' (Figure 17.37).

FIGURE 17.36
Querying the Floodmap of January and the Landtype Theme

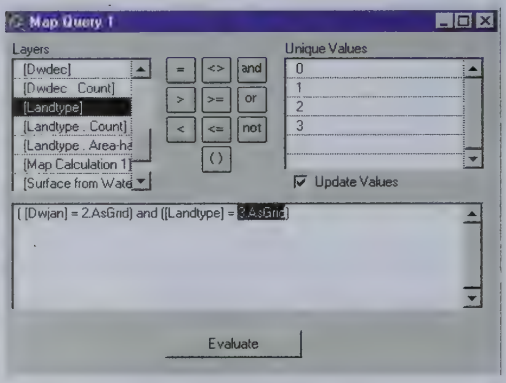
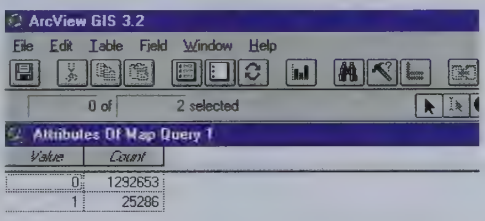


FIGURE 17.37
Number of pixels representing flooded F3 Land



How many hectares of F3 are flooded with a grid size of 10 metres?[34]

10. Save the query Theme as 'F3jan' (menu bar: **Theme/Save Data Set...**).
11. Query the 'Landtype' with the 'flood map of January' for F2 Landtype. Open the Theme Table of this query and you will see that there are 17243 pixels fitting the criteria 'F2 landtype' and 'flooded'. How many hectares F2 are flooded? Save the query as 'F2jan'.
12. Add the flood map for February ('DWFEB') to the View. Query the 'Landtype' with the 'flood map of February' for F3 Landtype. Open the Theme Table of this query and you will see that there are 22958 pixels fitting the criteria 'F3 landtype' and 'flooded'. How many hectares of F3 are flooded with a grid size of 10 metres? Save the query as 'F3feb'.
13. Query the 'Landtype' with the 'flood map of February' for F2 Landtype. Open the Theme Table of this query and you will see that there are 12 115 pixels fitting the criteria 'F2 landtype' and 'flooded'. How many hectares F2 are flooded? Save the query as 'F2feb'.
14. Continue the exercise for all months and fill in Table 17.6.

Tabulate Areas

Querying this way can be done quicker with Tabulate Areas which is in principle a cross-table query:

1. Make sure you have all flood maps added to the View (DWJAN, DWFEB, DWMAR, etc.). Go via the menu bar to: **Analysis/Tabulate Areas...**. The Tabulate Areas window will pop-up (Figure 17.38).
2. Select as Row Theme 'landtype' and as Column Theme the floodmap of the month you want to analyse, starting with January (Dwjan). Click **OK**.

[34] 252 ha, 1 pixel is 10 x 10= 100 m^2, 1 hectare is 10 000 m^2, or I pixel = 0.01 ha.

3. The calculated Table will pop-up (this table is saved automatically in the Tables part of the project). The areas are calculated in m^2 as the property settings of the view were in meters, so dividing by 10 000 will give you the hectares.

FIGURE 17.38
The Tabulate Areas window

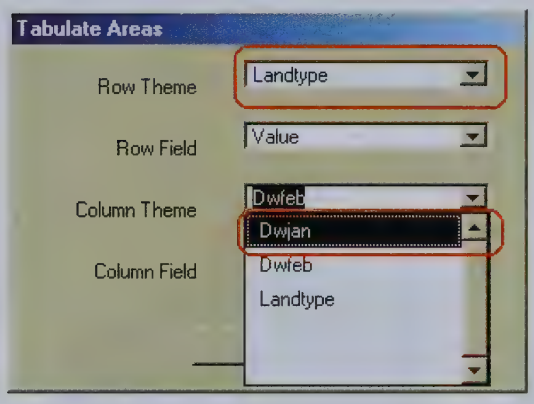
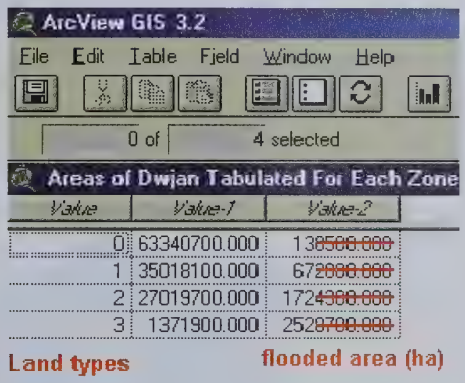


FIGURE 17.39
Calculated area in hectares



If you carried out the exercise properly you will find the areas as presented in Table 17.7. Using these data and the data in Table 17.6, the result will be an estimated catch of 111 metric tonnes/year for landtype F3 and 349 metric tonns/year for landtype F2.

TABLE 17.7
Estimated monthly flooded area for F3 and F2 landtypes in the CPP project area

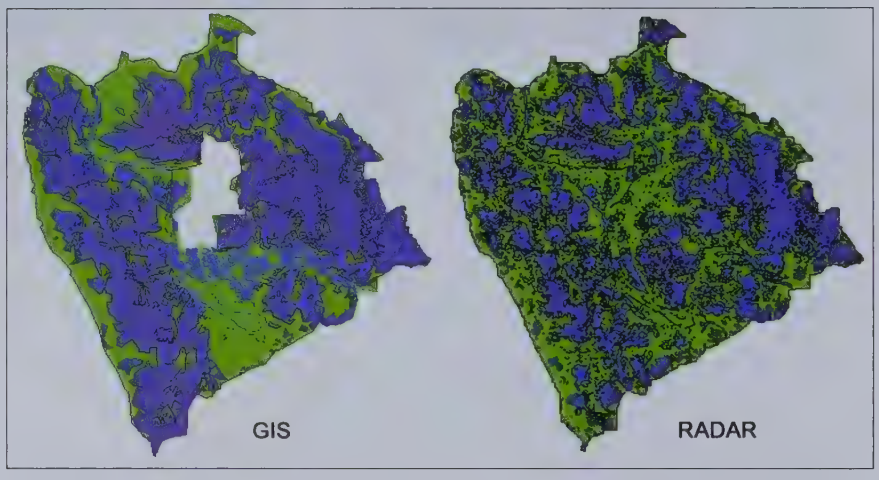
Month	F3 *(ha)*	F2 *(ha)*
January	252	172
February	229	121
March	227	99
April	236	123
May	324	254
June	360	658
July	375	2 576
August	378	2 793
September	379	2 828
October	370	1 410
November	358	563
December	302	259

The use of Radar images in floodplain fisheries in Bangladesh

Over the years developments in GIS and remote sensing have been tremendous. One of the most significant developments was radar satellite imaging able to penetrate the clouds. The major advantage is that during the flood season the extend of flooding can be assessed almost realtime from radar images. This is obviously less complicated than the method you have used during the previous exercise (interpolation of water levels over a project area with measured waterlevels at certain points, after which floodmaps need to be made).

A comparison of a flood map calculated with water levels in GIS and a flood map using radar images is presented in Figure 17.40.

FIGURE 17.40
Comparison between calculated flooding and Radar application



Querying radar images

1. Open ArcView, Open a New Project, a New View, check the working directory, and check that the map units and distance units in the View properties are set to meters. Add the Themes (Grid Data Source) 'radarjune', 'radarjuly', 'radaraugust', 'radaroctober', 'radarseptembe', and 'landtype' to the View (from the folder RW_03_Floodplain on your CD). If you want, you can load the legends 'Radar.avl' for the radar Themes, and 'landtype.avl' for the landtype Theme. The radar Themes show you the Radar images[35] for the months June, July, August, September, and October in the year 1998.
2. Query the radar Themes with the landtype Theme and calculate the flooded areas for F3 and F2 landtypes (as you have done in the previous exercise). You can do this either with Map Query (menu bar: **Analysis/Map Query...**) or with Tabulate areas (menu bar: **Analysis/Tabulate Areas...**).
3. Fill in Table 17.8 and compare the results between the calculated catches with radar images and with the generated floodmaps (GIS).

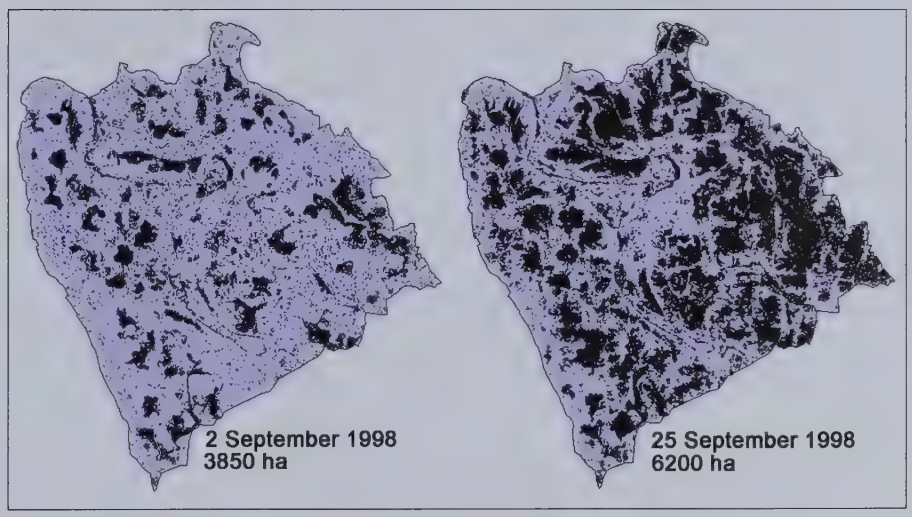
[35] The Images were processed and classified by the Centre for Environment and Geographical Information Systems (CEGIS), Dhaka, Bangladesh and provided by RADARSAT-1 images (c) Canadian Space Agency/Agence spatiale Canadienne 1998. Processed and distributed under licence by RADARSAT International.

TABLE 17.8
Comparison of fisheries analysis using radar or GIS data36

Month	F3		F2		CPUA		Total Catch Radar	Total Catch GIS
	(ha)		*(ha)*		*(kg/ha/month)*		*(metric tonnes)*	*(metric tonnes)*
	Radar	Interpolated	Radar	Interpolated	F3	F2		
June		172	1 404	1 042	22	19		24
July		285	2 300	2 440	16	38		97
August		306	2 428	2 541	13	44		116
September		305	2 419	2 535	14	85		220
October		172	1 280	1 182	220	99		155
Total catch							**632**	**612**

The differences between the two methods are small. The use of radar images could facilitate your work. However you have to realize one thing: Radar images give a flooded area on a given day of the month and not the average flooded area over the month as calculated by using GIS and water levels. The flooded area can be highly variable within one month, which means that the use of radar will only be accurate if more images are available per month. an illustration of different waterlevels in one month can be the radar images of the CPP area of 2 and 25 September 1998 (Figure 17.41).

FIGURE 17.41
Comparison of Radar images for two days in September 1998



[36] The GIS data and the CPUA for 1998 are from de Graaf *et al.*, 2001.

17.2 SURPLUS PRODUCTION MODELS AND GIS

Introduction

For the development of a fisheries management strategy, fisheries scientists and policy makers want to know what the present status of fish stocks is, and what the impact of fishing on these will be. Over the last decades a number of tools, or fish stock assessment models, have been developed that can visualize the interactive processes between fishing and fish stocks. One of these is the Surplus Production model.

The traditional surplus production models are those of Schaefer (1954) and Fox (1970). Surplus production models determine the optimum level of effort that produces the maximum yield that can be sustained without affecting long term productivity of the stock, also called Maximum Sustainable Yield (MSY). Further, surplus production models regard catch per unit of effort (CPUE) in relation to the fishing effort as basic input and assumes that biomass is proportional to the catch per unit of effort (f).

The surplus production models can be applied when reasonable estimates are available of total catch (by species), the catch per unit of effort (CPUE), and the related fishing effort (f) over a number of years. A prerequisite is that the effort must have undergone substantial changes over the period covered. Detailed information on surplus production models can be found in Sparre and Venema (1992) of which the basics are summarized below.

The Schaefer model plots CPUE as a function of the fishing effort (f) on a linear model with the form:

Y= a+bX, or, **CPUE = a + b* (fishing effort).**

Calculated Yield, Maximum Sustainable Yield (MSY) and the fishing effort for MSY (Fmsy) can then be expressed as:

Calculated Yield = a*(fishing effort)+b*(fishing effort)^2

Fmsy = - 0.5*a/b

MSY = - 0.25*a^2/b.

An example of a Schaefer curve, made for shrimp trawling in the Bay of Bengal (Table 17.9, [Mustafa and Khan, 1993]), is given in Figure 17.42.

TABLE 17.9
Shrimp trawling data from the Bay of Bengal

Year	Number of Trawels	Shrimp catch (metric tonnes)	CPUE (metric tonnes/ trawler)
1984	31	3 716	120
1985	31	4 178	135
1986	33	4 239	128
1987	33	3 338	101
1988	35	4 661	133
1989	37	2 621	71
1990	37	3 903	105
1991	40	3 116	78
1992	41	3 650	89
1993	41	3 237	79

FIGURE 17.42
Schaefer curve shrimp trawling in the Bay of Bengal

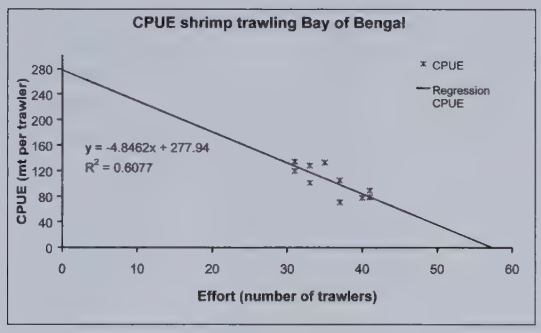
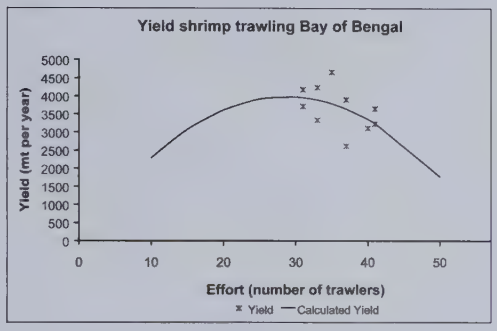


FIGURE 17.43
Yield curve shrimp trawling in the Bay of Bengal



Analysis gives:
CPUE = -4.85 * (Fishing effort) + 278 → **a = 278, b = -4.85**
Calculated Yield = a*(fishing effort)+b*(fishing effort)^2 → 278 * f + (-4.85) * f^2
Fmsy = -0.5*a/b → -0.5 * (278/(-4.85)) = **33 trawlers**
MSY = -0.25*a^2/b → -0.25 * (278*278)/(-4.85) = **3960 metric tonnes/year.**

The Munro and Thompson adaptation of Surplus Production models

Surplus production models are usually applied to long time series of CPUE and Effort. Munro and Thompson (1983a and 1983b), however, applied the surplus production models to a set of data from the Jamaican coral reef fisheries, all collected in the same year but representing different fishing grounds fished at different levels of effort. The basic assumptions for this adaptation of the Surplus production models are:

- The studied species are not very mobile, so each area has its own stock not mixing with the neighbouring stocks.
- The ecological regimes of different fishing grounds do not differ substantially, so the only differing impact on the stocks is the difference in fishing effort among the fishing grounds.

The fishery studied by Munro and Thompson (1983b) is a local trap fishery operated from canoes. Coral reef fish are not considered to be very mobile and it was assumed that each area has its own stocks which are independent of the neighbouring stocks (little mixing). The data used by Munro and Thompson and the resulting Schaefer curves are presented in Table 17.10 (Munro and Thompson, 1983a), Figure 17.44, and Figure 17.45.

TABLE 17.10
Jamaican reef fisheries data

Fishing ground	Effort *(canoes/km²)*	CPUE *(kg/canoe per year)*	Exploitation
A	1.63	2 367	Under exploited
B	0.38	3 279	Under exploited
C	3.09	1 407	Under exploited
D	5.63	556	Over exploited
E	4.43	974	Over exploited
F	5.51	1 306	Over exploited
G	4.58	564	Over exploited
H	4.20	767	Over exploited
I	1.49	1 875	Under exploited

FIGURE 17.44
Schaefer curve reef fisheries Jamaica

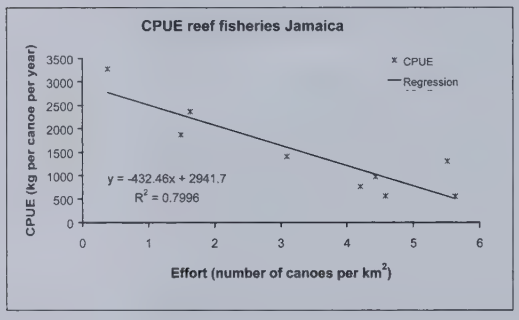
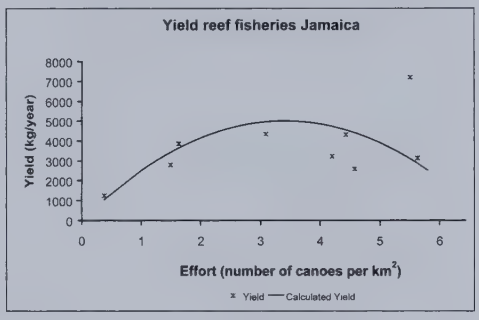


FIGURE 17.45
Yield of reef fisheries Jamaica



From the data and the Schaefer plot the following data can be deducted:
CPUE = 2 941.7 + [(-432.46) * (fishing effort)] → **a = 2 941.7, b = -432.46**
Calculated Yield = a*(fishing effort)+b*(fishing effort)^2 → 2941.7 * f + (-432.46) * f^2
Fmsy = -0.5*a/b → -0.5 * (2 941.7/(-432.46)) = **3.4 canoes per km^2**
MSY = -0.25*a^2/b → -0.25 * [(2 941.7*2641.7)/(-432.46)] = **5 002.5 kg per year.**

The Munro and Thompson adaptation of the Surplus Production models are not commonly known and used. However, it is clear that with the present development of GIS, they offer an opportunity to get some insight of the status of stocks within a relatively short time span (keeping in mind that the basic assumptions mentioned earlier should apply).

Therefore, two examples of this application will follow, one with Pais Pesca data and one using Mediterrenean fisheries data.

17.2.1 Fisheries on the Pescan lobster (*Cherax grafiensis*) in Lake Kadim

Apart from fisheries on carps and clupeids there is a small but highly valuable fishery on the Pescan lobster *Cherax grafiensis* in Lake Kadim. This fishery has the following characteristics:

- *Cherax grafiensis* is rather immobile. Tagging experiments have revealed that the lobsters remain in an area of about 3 km^2 during their whole life.
- *Cherax grafiensis* lives in water up to six metres deep, and its distribution is not related to other ecological factors such as phytoplankton, secchi disk, etc.
- The lobsters are caught by stationary traps placed on the bottom of the lake.

During the survey of the Department of Fisheries in 1999 (see page 70), the number of lobster traps were counted (Number of traps per ha) at the sampling areas and the owners of the traps were interviewed to get information on their annual catch (kg/year).

The spatial characteristics of the fishery allow analysing the data in GIS with an adapted Schaefer curve. For this the data were distributed over nine fishing zones, which are determined by the boundaries of the fishing areas of fishers from the villages located at the shore line of each zone.

There are two ways to carry out the analysis:

- Calculate the average values of fishing effort and CPUE per fishing zone with the data of the sample stations[37]. Construct a Schaefer curve and use the calculated values of **a** and **b** to calculate the F_{msy} (= -0.5*a/b). Interpolate a grid of the number of traps per ha (within the boundaries of the fishing zones) and find the over-exploited areas with the query: **[Number of traps per ha] > [F_{msy}]**.
- The second way is to generate the grids for **CPUE** and **Number of traps per ha**. Then carry out a grid regression between the two and use the obtained values of **a** and **b** to calculate **F_{msy}**. The last step is to query the effort grid to find the over- and under-exploited areas (under-exploited: **[Number of traps per ha] < [F_{msy}]**).

This second method is demonstrated below:

1. Start ArcView, Open a New Project, New View. Add the following Themes from the '18_Lake_Kadim_Lobster' folder: 'Lobster data.shp' (containing all lobster data from the different sampling sites in Lake Kadim), 'depth.shp', 'fishing zones.shp', 'fishing villages.shp', 'Lake Kadim boundary.shp', and 'Pais pesca country.shp'.
2. Check the working directory, the projection (Equal area cylindrical), and properties settings.
3. Make the 'Fishing zones.shp' Theme active, and use the 'Zoom to active Theme(s)' button in the buttonbar to zoom to this Theme.
4. As you are going to work within the fishing zones only, you will first need to make a grid of the 'Fishing zones.shp' Theme[38] (output grid size 100 metres, so each pixel equals 1 hectare). Save this grid as 'Zones'.
5. Set the grid 'Zones' as mask. (Analysis/Properties...).
6. Make the Theme 'Lobster data.shp' active, and make a surface grid[39] of the 'CPUE' with 'IDW' and a 100 metres grid cell size, with the Output Grid Extent: Same As Display. Rename the new grid (Theme/Properties...) and save and rename the Theme as 'CPUE' (Theme/Save Data Set...).
7. Make another grid for fishing effort ('Number of traps per ha', you will see only 'Number_of_' in the drop-down field) and save and rename the grid as 'Effort'.
8. Activate the Grid Regression extension (File/Extensions...).

[37] See Calculating Averages in a Theme table at page 127.

[38] Make the Theme 'Fishing zones.shp' active, go to Theme/Convert to Grid... in the menu Bar, name your file ('Zones'), Output Grid Extent: Same As Display, Output Grid Cell Size: 100 m, Conversion Field: 'Zone_code', Join feature attributes to Grid, Add Grid as Theme to the View.

[39] Also create this grid with Kriging, see Annex C.

9. Click on the regression button and make a regression with CPUE as dependent and effort as independent. (see the chapter: Regression analysis of Lake Kadim data using an avenue script, page 84). The results should be like Figure 17.46 and Figure 17.47.

FIGURE 17.46
Regression result outcome

REGRESSION RESULTS

DEPENDENT GRID: CPUE
INDEPENDENT GRID: Effort
MASK GRID: Zones

Report saved to:
d:\tempgis\regression12.txt

VECTOR-based Regression Output:

DESCRIPTIVE STATISTICS: Point Count = 8636

--- CPUE [Dependent/Response] ---
Mean: 21.7774
Minimum: 0.2814
Maximum: 85.1437
Range: 84.8623
St. Dev: 8.0357
Variance: 64.5730
Sum: 188069.7434

--- EFFORT [Independent/Predictor]---
Mean: 5.5500
Minimum: 1.0007
Maximum: 17.8833
Range: 16.8826
St. Dev: 2.8775
Variance: 8.2802
Sum: 47929.5580

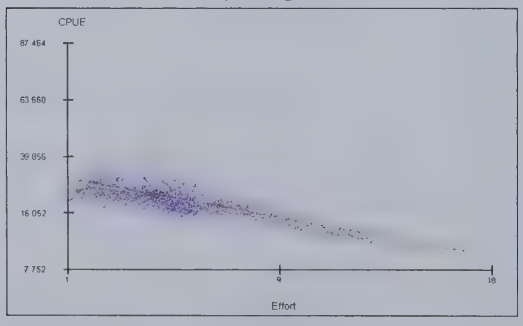
Regression Equation: y = -1.95440111288166x + 32.62432617649320
r-squared = 0.48979906458982

ANOVA Table
Dependent Grid: CPUE

	Df	Sum of Sq	Mean Sq	F-Value	P-Value
Effort	1	273106.017	273106.0174386	8288.7443436	0.0000000
Residuals	8634	284481.854	32.9490217		
Total	8635	557587.871			

Report Generated Thursday, May 30, 2002 10:22:26

FIGURE 17.47
Scatterplot regression

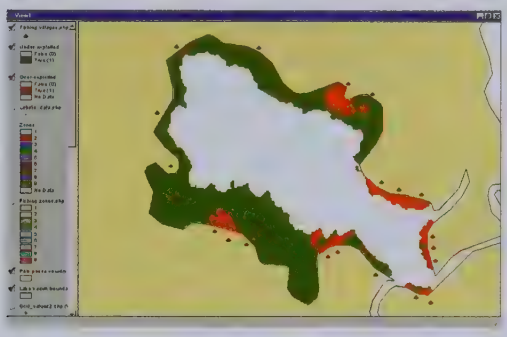


10. Use the obtained values of **a** and **b** to calculate F_{msy}, and MSY[40].
11. Find over- and under-exploited areas, using the Map Query function (**Analysis/Map Query...**) (over-exploited: effort > F_{msy}, under-exploited: effort < F_{msy}. (Figure 17.48)).

[40] If you did the analysis correct, you have found the F_{msy} = 8.35, MSY = 136.1.

This example has given clear results. However, in the real world, cases with such nice results are not easy to find. Regressions between grids often provides a cloud of points, and zonation is often not that easy and clear-cut. But even in those cases there are some new developments which can be applied on Surplus production models in GIS. Therefore a more complex example of fisheries in the Mediterranean Sea is provided.

FIGURE 17.48
Exploitation status of lake Kadim, areas in green underexploited, areas in red over-exploited.



Note: Calculating averages in a Theme table

ArcView has a very neat function to calculate averages within a Theme table. This is best explained through an example:

1. Start ArcView, Open a New Project, New View. **Add** the following Theme from the '18_Lake_Kadim_Lobster' folder: 'Lobster data.shp' (containing all lobster data from the different sampling sites in Lake Kadim). You will see the fieldheaders: 'Shape', 'Id', 'Zone_code', 'Cpue', 'Attractor', and 'Number_of_'. Check the working directory.
2. Press the header of the field 'Zone_code', so that it appears pressed. Go to the summarize function (menu bar: **Field/Summarize...**, or the summarize button in the button bar next to the calculator). The Summary Table Definition window will pop up.
3. Select the field in the dropdown list next to 'Field:' of which you want to know the average per 'Zone_code'. Select 'Cpue'. Then you need to select the function in the dropdown list next to 'Summarized by:' by which the field needs to be summarized, in this case 'Average'. then press **Add**, and you will see the term 'Ave_Cpue' appear. Press **OK**.

The screen of sum1.dbf appears with the average values of CPUE per zone (Figure 17.49).

FIGURE 17.49
Summary of 'Lobster data.shp' per fishing zone

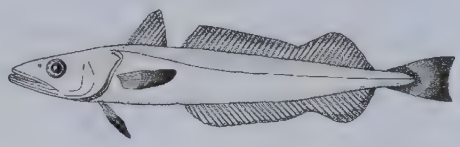
sum1.dbf

Zone_code	Count	Ave_Cpue
1	46	10.0547
2	34	10.5295
3	69	20.9734
4	58	29.3891
5	72	30.3993
6	93	22.3809
7	130	23.6057
8	60	25.2982
9	60	7.8928

17.2.2 Fisheries on the European hake (*Merluccius merluccius*) in the Mediterranean Sea

The European Hake (*Merluccius merluccius*) is a highly valuable demersal fish in the Mediterranean Sea. It lives close to the bottom, usually between 70 and 370 metres at daytime but moves off bottom at night.

FIGURE 17.50
The European hake (*Merluccius merluccius*)



European hake has been an important food for the western Europe population throughout history. It is primarily caught by bottom and pelagic trawls, but also with longlines, bottom-set gillnets and Danish seines. The total reported catch for this species was 71 627 metric tonnes for the year 2000. The countries with the largest catches in this period were Spain (24 853 metric tonnes) and Italy (9 291 metric tonnes) (FAO, 2000). During the mid-1990s several experimental surveys were carried out near the Tyrrenian coast of Italy. With this data Corsi, Agnesi and Ardizzone (2001) developed another approach to surplus production models in GIS.

A Munro and Thompson plot for Hake data in the Mediteranean

Corsi (2000a) carried out an analysis in GIS on catch and effort data obtained over the period 1994-1996. The following data were used:

- Port (being the main landing sites of the different fishing zones) statistics. The data encompass fishing effort expressed in gross tonnage of the trawling fleet per km^2, and CPUE expressed in kg per hour of trawling.
- Data of three experimental trawl surveys carried out at 130 georeferenced randomly selected sampling stations. The mean yields per hour were interpolated by means of Universal Kriging over the entire study area to derive a CPUE surface over the entire area.
- A grid representing the fishing effort over the entire study area, made with deductive modeling which allocates the port's nominal fishing effort throughout the port's fishing ground, based on a combined function of depth and distance from the port (Corsi, 2000b).
- Major fishing zones in the area.
- Data of a bathymetric survey, providing the bottom depth over the study area

With the available data, i.e. spatial distribution of Fishing effort and CPUE, the Munro and Thompson approach could be used to estimate F_{msy}, and to locate over-exploited areas.

1. Start ArcView, Open a New Project, New View. **Add** the following Themes from the '19_Hake_analysis' folder: 'Fishing zones.shp', 'Ports.shp', 'Coastline.shp' and 'Hake data.shp'.
2. Check the working directory, the projection and activate the Grid Regression extension[41]. While checking the projection you will get an information screen telling you: 'It appears that your data is not in decimal degrees. Do you want to attempt to project anyway?'. Click **No**. This message will appear whenever your data is not in decimal degrees. For this exercise you do not need to project the data. For more information on projections, please see the chapter: Projection, on page 40.
3. The Theme 'Hake data.shp' contains data on the spatial distribution of fishing effort and CPUE. Make two grids from this Theme, one for effort (**Theme/Convert to Grid...**, Gridname: 'Effort_Hake', Output Gird Extent: Same

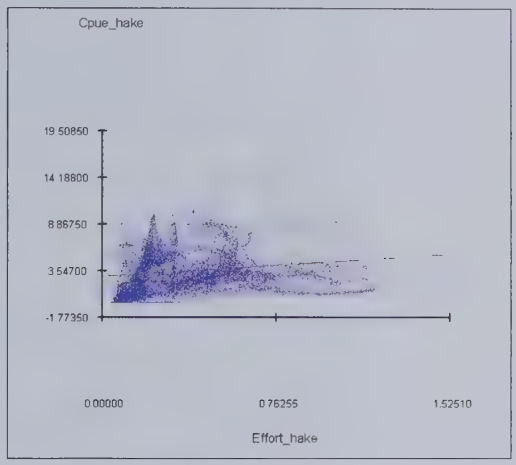
[41] File/Extensions...

As Display, Output Grid Cell Size: 1 000 Map Units, field for cell values: 'Effort'), and the second on CPUE (same parameters, except for the name: 'CPUE_Hake' and the field for cell values: 'CPUE').

FIGURE 17.51
Regression results

```
REGRESSION RESULTS

DEPENDENT GRID: Cpue_hake
INDEPENDENT GRID: Effort_hake
MASK GRID: No Mask Grid used in analysis

Report saved to:
d:\tempgis\regression13.txt

VECTOR-based Regression Output:

DESCRIPTIVE STATISTICS:  Point Count = 20636

— CPUE_HAKE [Dependent/Response] —
   Mean: 3.6111
   Minimum: 0.0000
   Maximum: 17.7350
   Range: 17.7350
   St Dev: 2.6582
   Variance: 7.0661
   Sum: 74518.4920

— EFFORT_HAKE [Independent/Predictor]—
   Mean: 0.4137
   Minimum: 0.0000
   Maximum: 1.5251
   Range: 1.5251
   St Dev: 0.2756
   Variance: 0.0759
   Sum: 8536.1152

Regression Equation: y = 1.62388871933571x + 2.93929723681082
r-squared = 0.02833719934270

ANOVA Table
Dependent Grid: Cpue_hake

             Df      Sum of Sq      Mean Sq      F-Value   P-Value
Effort_hake   1       4131.842   4131.8416194  601.7619938 0.0000000
Residuals 20634     141677.974      6.8662389
Total     20635     145809.815

Report Generated Thursday, May 30, 2002 13:11:41
```

FIGURE 17.52
Scatterplot regression of 'CPUE_Hake' vs 'Effort_Hake'



4. Click on the regression button and make a regression with 'CPUE_Hake' as dependent and 'Effort_Hake' as independent.

From the regression analysis (Figure 17.51 and Figure 17.52) you see that the results are not valid for our purpose; the regression has a positive slope (b = 1.62).

5. Add from the '19_Hake_analysis' folder the Theme 'Depth.shp', and make it visible (Figure 17.53). You can see that the fishing zones have a large variation in depth. Hake is a bottom dweller, which means that, for this species, the Fishing Zones are not homogenous ecologically, and thus one of the basic assumptions of the Munro and Tompson model is violated.

FIGURE 17.53
Depths at the Tyrrenean coast

6. Save your project as 'Hake.apr' or another name of your choice.

Developments continue and Corsi (2000a) developed a model to overcome the problem of different ecological fishing zones or varying stock densities. The model is still in its theoretical stage and its merits have to be further studied. However, its simplicity makes it of interest to include it in this manual.

A Corsi type analysis of Hake data in the Mediterranean

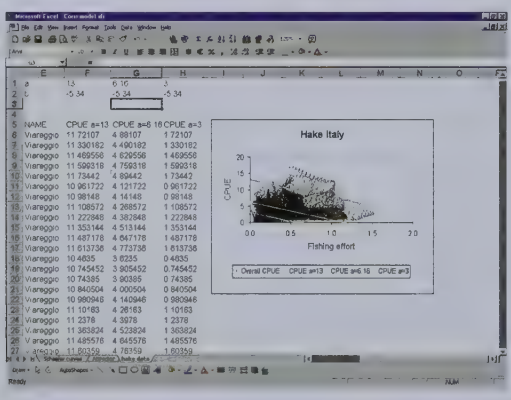
The basic assumption behind the analysis developed by Corsi is that the slope (b) of a Schaefer curve remains constant with different ecological zones while the intercept (a) changes with these zones.

This can be explained with the data in the spreadsheet 'Corsi model.xls'. Open this spreadsheet 'Corsi model.xls' (using Microsoft Excel) from the folder '20_Corsi_model' and open the worksheet 'Schaefer curves'.

In the worksheet, you see the average fishing effort and CPUE per different fishing zones, as obtained from port statistics. Make the Schaefer curve (effort vs CPUE) for the data. Do a lineair regression on the data, of which the result should be Y = 6.16 – 5.34*X (**a = 6.16** and **b = 5.34**), or **CPUE = 5.34 * effort + 6.16.**

Open the worksheet 'hake data'. In this worksheet you see a graph (Figure 16.54) with a cloud of dots, which are the data points of 'Effort vs CPUE' from the Effort and CPUE grid, and three straight lines, three Schaefer curves with the estimated value of the slope; **b = 5.34** and three different values of **a**.

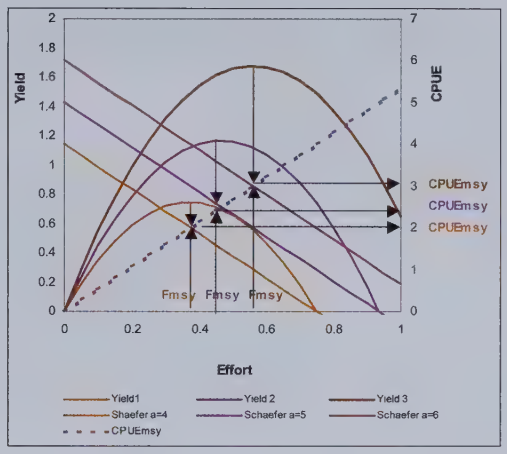
FIGURE 17.54
The worksheet of hake data



For each Schaefer curve F_{msy} and its related CPUE at F_{msy} ($CPUE_{msy}$) can be calculated. This basic function for the Corsi model is described by $\mathbf{CPUE_{msy} = -b * Fishing\ effort}$. This function is called the **attractor**.

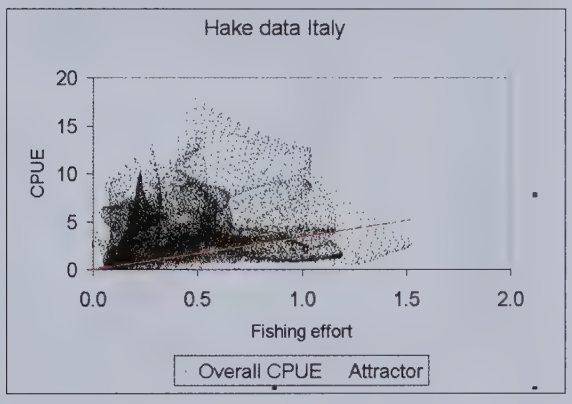
Open another spreadsheet: 'The attractor function.xls'. Yields and CPUE are calculated for three Schaefer curves with the same slope (b) in this spreadsheet. For each curve you see (Figure 17.55) that the relation between F_{msy} and $CPUE_{msy}$ is lying on the straight blue line; $\mathbf{CPUE_{msy} = 5.34 * Fishing\ effort.}$

FIGURE 17.55
The attractor function



If assumed that the cloud of data points for effort vs CPUE for the Hake data is made up of an infinite number of parallel running Schaefer curves for an infinite number of fishing zones then the attractor function can be used to divide the cloud in points below the attractor line, with a CPUE below $CPUE_{msy}$ (or over-exploited points) and above the attractor lines with a CPUE above $CPUE_{msy}$ (or under-exploited points) (Figure 17.56).

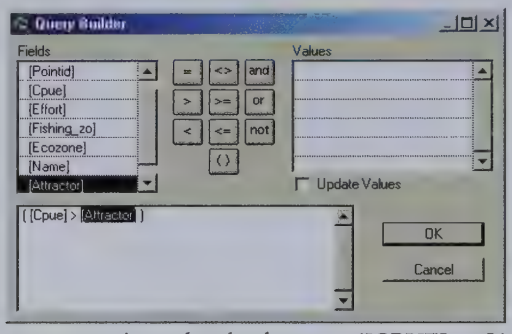
FIGURE 17.56
Schaefer curve hake fisheries Thyrrenean coast



Try to apply the model in ArcView:

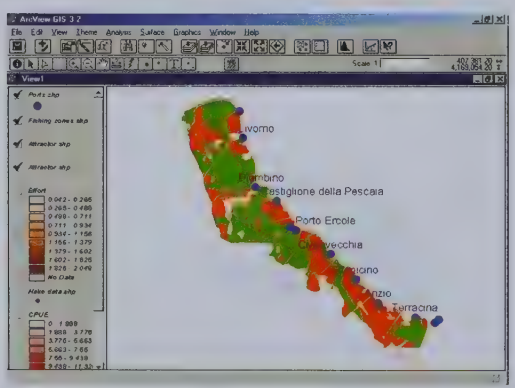
1. Open ArcView, open the previously saved project 'Hake.apr'. Add the Theme 'Attractor.shp' from the '20_Corsi_model' folder to the View. Open the Theme Table.
2. Start editing the table. Add the numeric Field 'Attractor' with 4 decimal places.
3. Calculate the field (**Field/Calculate...**) by entering '**[effort] * 5.34**'. Stop editing of the table and save the edits.

FIGURE 17.57
The query for under-exploited areas in the Thyrrenaen Sea



4. Open the Theme properties and make the query '**[CPUE] > [Attractor]**', which gives you the under-exploited data points. Change the color of the data points in green.
5. Copy and paste the Theme into the same view, make only the newly pasted Theme active, open the Theme properties again and make the query '**[CPUE] < [Attractor]**', which gives the over-exploited data points. Change the color of this Theme in red. Now you have the distribution of over- and under-exploited areas in the Thyrrenean Sea according to the Corsi model (Figure 17.58).

FIGURE 17.58
Over- and under-exploited areas in the Thyrrenean Sea according to the Corsi model



Note on the use of this model in general

For the application of surplus production models in GIS of course the same cautious approach as used in traditional applications of surplus production models should be adhered to, as they tend to give falsely optimistic answers. Please refer the handbooks on this subject; Gulland (1985), Pitcher and Hart (1982), Quin and Deriso (1999), Hilborn and Walters (1992).

18 How to proceed with your own GIS work

Until now you have made a large number of exercises using GIS. These exercises have given you an insight in the vast possibilities of GIS. Your problem now (after having finished this manual) is to apply these techniques to your situation, with your data. You probably do not have your data in similar files as the ones you used for the exercises in this manual. There are several sources for these types of files; most likely your country will have a national agency/institute for this type of information. Probably the Geography department of your national University will be able to point you to the right people. There are many public access sources on the internet, as www.esri.com, General Bathymetric Chart of the Oceans (http://www.ngdc.noaa.gov/mgg/gebco/gebco.html), etc. A look in search engines on the web will give results for specific data.

However, sometimes you will not be able to find the data you need, or you do not have the resources to acquire them. So the only solution is to make the files yourself. If you develop your own data sets in a GIS, you have to realize a very important issue, which is **Quality of Data**. Specialized GIS institutions can make high quality digitized Themes/layers as they use digitising tables and special software. With limited resources it will be difficult for you to reach their standards. However, with ArcView you can make Themes to analyse data of your own study area. In this chapter some guidelines are provided to create your own Themes/layers.

As you can imagine, there are three principle aspects when you are creating your own Themes/layers:

- Georeferencing of the data. This is of utmost importance to avoid spatial distortion in areas and distances of your data as discussed in the Chapter Projection, on page 40.
- Digitising your maps/images. The result of this will be a Theme (or several Themes) with points, and/or polygons, and/or lines.
- Registering the images. It is important that ArcView knows the exact place in the mapped area where your data must be allocated to. When you register an image, map, data, you give ArcView georeferencing information of the image involved.

Once you have registered a Theme, map, or something similar, field data can be added to the Theme (see chapter Putting field data into a GIS, page 36).

18.1 REGISTERING AND DIGITIZING AN IMAGE

Making your own GIS starts with maps, aerial photographs, etc, of the area you are interested in, after which data is added. An example of a map is presented in Figure 18.1, where the results of a biodiversity study in the floodplains of Pais Pesca are presented. In the figure you see sampling stations (red circle with cross), water bodies (dark blue), villages (brown), rice fields (green), roads (dark brown/red), etc. What is more important, the latitudes and longitudes are clearly indicated. With this information this figure is georeferenced, and can be registered into ArcView.

Registration of images in ArcView can be done with an Avenue script, written by Mark Cederholm[42]. This extension will be used in the next exercise.

[42] The script is provided on the CD but can also be downloaded from http://www.pierssen.com/ArcView/ArcView.htm. The name of the downloadable file is 'stuff.zip'.

FIGURE 18.1
Pais Pesca floodplain biodiversity study

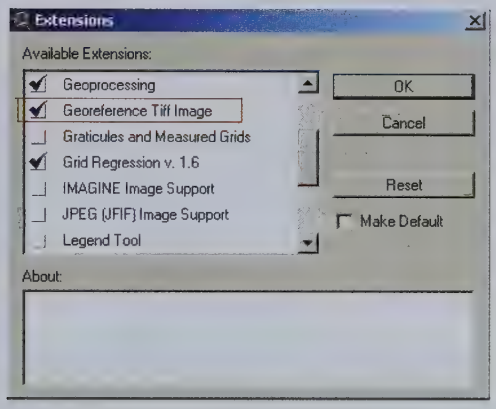
18.1.1 Registering

Only '.tiff' and '.bmp' images can be registered into ArcView with Cederholm's extension. So when you scan an image, or make the image yourself, you have to make sure you save it as a '.tif' or '.bmp' file. You can find the file containing the above figure in the folder 'RW_05_Geo' with the file name: 'Pais_Pesca_Biodiv_floodplain.tif'. First you have to copy this folder onto your hard disk, before you start working with this file (from the hard disk).

Before you can register this image, you will have to install Cederholm's extension. Copy the file 'Georeference Tiff image.avx' from the folder 'Extensions/Geo_ref' on the CD to the folder of which the path ends like: ESRI\AV_GIS30\ARCVIEW\EXT32 on your hard disk.

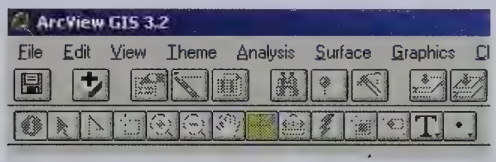
1. Open ArcView; open a new View.
2. Set the working directory.
3. Set the projection to Category: 'Projections of the World', and Type: 'Geographic'.
4. Activate via **File/Extension...** the 'Georeference Tiff Image' extension (Figure 18.2).

FIGURE 18.2
Georeference Tiff Image extension



After this activation, you will see that on the button bar a new green button has appeared, the colour of the button is rather diffuse (Figure 18.3).

FIGURE 18.3
The new Georeference Tiff image extension button



5. Add the image to the View. The image can be found in the file 'Pais_pesca_Biodiv_floodplain.tif', which is located in the folder 'RW_05_Geo'. Remember that when you add this file to the View to change the data source type to 'Image Data Source' in the Add Theme window. Do you notice that the button of the Georeference Image extension has become brightly green? (Another point to remember: If you copy a file from a CD, its properties will be copied as well. In the case of a file on a CD, these are automatically set as read only. Remove this read only property as described on page 5.

The Georeference Tiff Image extension is straight forward. Two points on an image are selected, located diagonally and as far from each other as reasonably possible. Enter the geographic location of the two points and the map will be registered in ArcView. However, remember, ArcView works with Decimal Degrees (DD) and the map from the file contains the more commonly used Degrees, Minutes, and Seconds (DMS) system. Remember how to convert DMS into DD[43] (see Chapter: Points and degrees, page 35).

In the map we encircled the two points you need to use for this exercise (Figure 18.1), with the following coordinates:

TABLE 18.1
Georeferencing points of figure 18.1

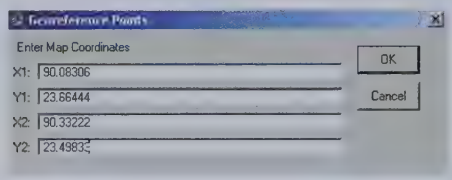
	Longitude *(DMS)*	Latitude *(DMS)*	X *(DD)*	Y *(DD)*
Point 1	90° 04′ 59″	23° 39′ 52″	90.08306	23.66444
Point 2	90° 19′ 56″	23° 29′ 54″	90.33222	23.49833

6. Zoom in on Point 1, and press the Georeferencing Image button in the toolbar.

[43] DD= Degree + Minutes/60 + Seconds/3600.

7. Your pointer is now changed into a little cross (the georeference pointer). Place this cross on the crossing of the longitude and latitude lines in the red circle, and select this point by clicking your mouse.
8. The message 'Point collected' appears, press **OK.**
9. Zoom to Full Extent, zoom in on Point 2, press the Georeferencing image button again, place the cross (georeference pointer) on the crossing of the longitude and latitude lines in the red circle, and select this point by clicking your mouse.
10. The message 'Use current point to complete rectangle?' appears, press **Yes**.
11. The Georeference Points window pops up, where you are requested to 'Enter Map Coordinates' (Figure 18.4). Use the DD-coordinates from the table above and press **OK**.

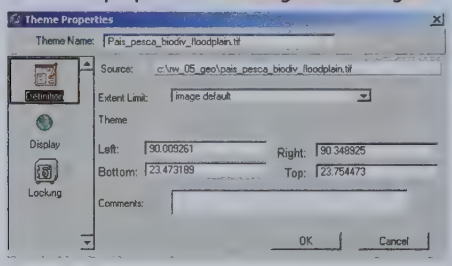
FIGURE 18.4
Georeference Points window



12. After you have pressed **OK**, you will see that the View goes back to Full Extent. If you move the pointer over the View you will see that the coordinates (in the top right corner) are changing.

The image is now registered in this project. To check the registering process, open the Theme Properties, and you will see values for the Left, Right, Bottom and Top sides of the Theme (Figure 18.5).

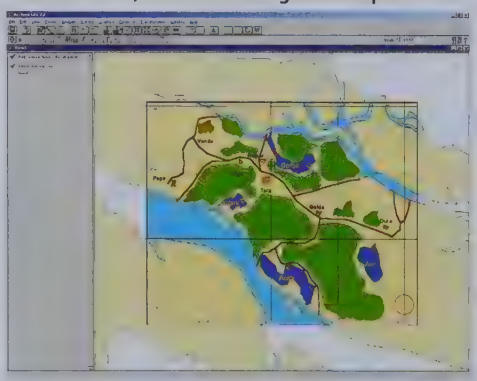
FIGURE 18.5
Theme properties of the registered image



13. Save the project with a name of your own choice (menu bar: File/Save Project)

You can check if the image was registered correctly by Adding the Theme

FIGURE 18.6
Two Themes, to check the registration process



'Flood_district.shp' from the folder '12_calc_with_grids' on your CD (remember that the Data Source Type of this Theme is Feature Data Source). After you have added this Theme, Zoom out, and you will see that the image fits perfectly into the 'flood_district.shp' Theme (Figure 18.6).

14. Close the Project, exit ArcView.

With the exercise above you have learned how to register an image on which coordinates were clearly indicated. However, it is possible that coordinates are not clearly indicated on an image. You can still reference such an image as long as you have the exact coordinates of two locations on the map.

The longitude and latitude of the villages in the 'Pais_pesca_Biodiv_floodplain.tif' image were recorded with a GPS and are presented below, with the corresponding XY coordinates. The next exercise is to register the image with the GPS readings of the villages Vanda and Dura.

TABLE 18.2
Coordinates of villages in figure 18.1

Village	Longitude *(DMS)*	Latitude *(DMS)*	X coordinate *(DD)*	Y coordinate *(DD)*
Vanda	90° 05′ 02″	23° 43′ 14″	90.08389	23.72056
Tara	90° 10′ 33″	23° 39′ 17″	90.17583	23.65472
Pepe	90° 03′ 38″	23° 39′ 01″	90.06056	23.65028
Volga	90° 08′ 39″	23° 40′ 41″	90.14417	23.67806
Neman	90° 09′ 20″	23° 40′ 45″	90.15556	23.67917
Dura	90° 18′ 29″	23° 35′ 48″	90.30806	23.59667
Golda	90° 13′ 30″	23° 36′ 52″	90.22500	23.61444

1. Start ArcView, open a new View.
2. Set your Working directory.
3. Set the projection (Category: Projections of the World, Type: Geographic).
4. Activate the Georeference Tiff Image-extension (**File/Extensions...**).
5. Add the Image (Image data source) 'Pais_pesca_Biodiv_floodplain.tif' located in the folder 'RW_05_Geo' to the View.
6. Click the Georeference Image-button.
7. Place the georeference pointer in the centre of the village Vanda and click your mouse, a pop-up window shows again, with remark: 'point collected', press **OK**.
8. Place the georeference pointer in the centre of the village Dura and click your mouse. You will be asked: 'Use current point to complete rectangle', press **Yes**.
9. Enter the Map Coordinates of Vanda and Dura and press **OK**.
10. Add the Theme 'Flood_district.shp' from the folder '12_calc_with_grids' on your CD again and check if you registered the image correctly.
11. Take care: the XY coordinates are not attached to the Theme. If you open the open the Image Theme in a new project, you will have to repeat the above described procedures. However, if you save the project, the coordinates will be added automatically when the project is opened.
12. In order to attach the coordinates to the image file you need to convert the image into a World tiff-file. This is easily done with a small script 'make a world file.avx' also written and provided by Mark Cederholm.
13. Copy the file 'Make a world file.avx' from the folder /Extensions/Geo_ref/ on the CD to the folder of which the end of the path looks like: 'ESRI\AV_GIS30\ARCVIEW\EXT32' on your hard disk.
14. In the **File/Extensions** menu activate the Make a World file extension.
15. On the button bar, the Make World File button appears.
16. Make the to be converted Image active (remember: pressing the legend of the Theme once, so that it looks like is a bit elevated). In this case the 'Pais_pesca_Biodiv_floodplain.tif'.

17. Click the Make World File button.
18. A message 'Done' will pop up, press **OK**.

The extension has created a new small file with the extension '.Tifw' where information on the coordinates is stored. As long as the original '.tif' file and this '.Tifw' file are located in the same folder, opening the '.tif' file in a new View will result in an Image which is registered.

19. Close the Project and exit ArcView.

You can now proceed to digitize the data on the referenced map as explained below.

18.1.2 On screen digitizing in ArcView[44]

From your registered Image you can now abstract any data you need by digitising in ArcView. The newly created themes will automatically encompass the geo reference and can be further used to analyse your data in ArcView. Digitising is in principle nothing more then accurately tracing lines, polygons, points, etc. on your screen and saving them as a new theme.

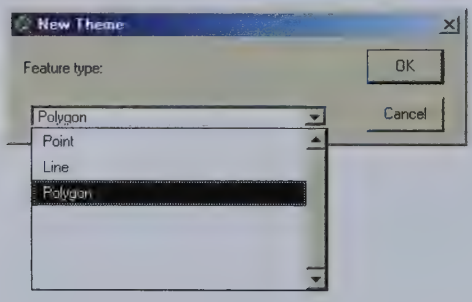
The next exercise will show you how to do this by digitising the water bodies in the floodplain of Pais Pesca

1. Open ArcView and a new View.
2. Set your working directory.
3. Set the projection (Category: Projections of the World, Type: Geographic).
4. Add the image 'Pais_pesca_Biodiv_floodplain.tif' from the folder you used to work from in the previous exercise.
5. Check if the image is registered; in the upper right corner you should see values around 90 and 23. You could also check the Theme Properties table, menu: **Theme/Properties...**, see Figure 17.5).

If the image is not registered, go back to the previous exercise (where you used the 'Make a world file' extension), and try again to make the file with the '.Tifw' extension. Make sure you save this file in the same folder as where the Image file is located that you use in this digitizing exercise.

6. Go via the menu bar to **View/New Theme...**. In the dialogue box select 'Polygon' as the Feature type from the drop-down menu (Figure 18.7) and press **OK**.

FIGURE 18.7
The New Theme dialogue box



7. In the next dialogue box specify where to save the new Theme. Give the Theme a name, for the exercise you do now you can use the name: 'Water_bodies.shp'. press **OK**.

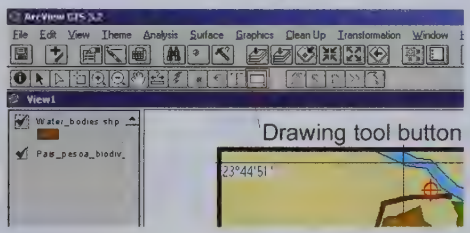
[44] Adapted from an exercise provided by Paul Eastwood and Geoff Meaden.

A new Theme is now added to the View, which at the moment contains no features. The check box for the 'Water_bodies.shp' Theme in the View's Table Of Content has a dashed line around it, indicating that the Theme can be edited (Figure 18.8).

FIGURE 18.8
Table Of Content indicating which Theme can be edited

8. From the button bar select the Drawing Tool button. The Drawing Tool button is the tool button in the second row, far right (Figure 18.9).

FIGURE 18.9
The Drawing Tool button



9. Move the pointer to the Drawing Tool button, click and hold the mouse button to bring up a drop down list of the Drawing Tool buttons. Select the Draw Polygon button .
10. Zoom in on the water body you want to digitize (for this exercise select Jugini). After you have zoomed in on the waterbody, and made sure you have pressed the Draw Polygon button, you need to trace the outer borders of the waterbody with the pointer. Place the pointer on the position where you wish to start and click once. Move the pointer over the outer border, clicking every point where you change direction (Figure 18.10). After you have followed the outline of the waterbody, and have returned to your starting point, make a double-click, indicating you have finished the polygon (Figure 18.11).

FIGURE 18.10
Following the outline of a waterbody

FIGURE 18.11
The completed polygon. See the eight squares around it, indicating it is active

11. If you have made a mistake you can always delete the polygon you made and start over: After you completed the polygon, you will see there are eight squares around it. This means the polygon is active, and you can delete it. If these squares are not around the polygon, you first have to activate it. Select the polygon by using the Pointer tool . First press the Pointer tool button in the button bar, then move the pointer to the polygon you want to delete, and click it (you will see eight squares appear around the polygon, meaning the polygon is active). When you now press the delete button on your keyboard, you will delete the polygon.

The first digitising is always a little bid rough and the shape you made never overlaps nicely with the original shape. So you have to continue editing.

12. To be able to edit the shape of the new polygon, you need to see the outline only: Go to the Legend Editor of the new Theme (either by double clicking on the legend, or through **Theme/Edit Legend...**), double click on the Symbol, the fill palette comes up, click on the colour button, select in the Color dropdown box 'Foreground', select the square with the cross, indicating you do not want any colour as foreground. After this, select in the Color dropdown box 'Outline', select a colour for the outline (in this example red is used). Close the Fill Palette, press **Apply** in the Legend Editor and close the Legend Editor (Figure 18.12).

FIGURE 18.12
The polygon, after changing the Legend to show only the outline in red

FIGURE 18.13
The polygon, after pressing the Vertex Edit tool button

13. Click on the Vertex Edit tool button and you will see the outline of your Theme with small squares indicating the places were you clicked your mouse (Figure 18.13).
14. Zoom in on a part of the outline of the Polygon and press the Vertex Edit tool button again. You can now adjust the shape of the polygon (as explained below) until its outline follows the shape of the original image.
15. Move the pointer onto one of the squares, you will see that once you are on the square the pointer changes from an arrow into a cross. As soon as the pointer is changed into a cross, you can move the square on the outline by clicking your mouse keeping the mouse button pressed, moving the square to the spot where you want it and release the mouse button ('drag and drop'). By doing this you can change the shape of the polygon.

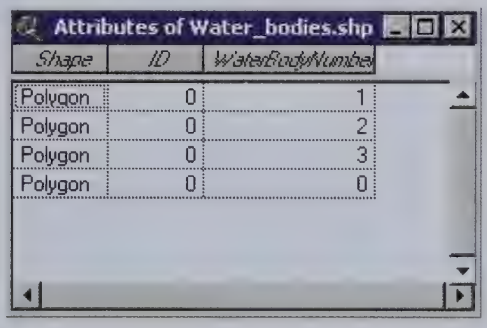
If you need more points where the direction of the outline changes, you can add a square to the outline. Move the pointer to the outline, and you will see that it changes from an arrow to a circle with a cross inside. Once you see this, you can click your mouse. By doing so, you have added a square which you can move around as described above.

Once you are satisfied with the outline of the digitized water body, use the same procedure to digitize the other water bodies of the Image, each time starting with using the Draw Polygon tool button.

16. After you have digitized all polygons satisfactory, the editing session should be ended: Go via the menu bar to **Theme/Stop Editing**. A message will pop up asking you 'Save edits to Water_bodies.shp' Press **Yes** to save your edits.

17. Open the Attributes table of the 'Water_bodies.shp' Theme. You will see only two columns. You might want to add a field to add the names of the different

FIGURE 18.14
The Attributes table of the New Theme, with the added field 'WaterBodyNumber'

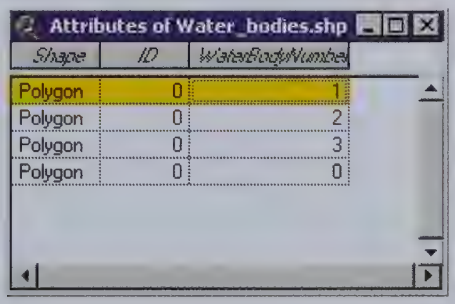


waterbodies. In Chapter 'How to edit your Theme table and do calculations?' on page 31 is explained how to add a field to an attribute table. One problem rests though, and that is how to know which record belongs to which polygon. As explained in the same chapter, you can edit the table by adding a field for the names of the different water bodies. Now add per record a number (Figure 18.14).

Now you have to determine which record belongs to which polygon: Press the Select tool button on the button bar.

18. Select one record in the attribute table by moving the pointer to a record, click your mouse. You will notice that the record you selected becomes yellow.

FIGURE 18.15
The Attributes table with a record selected



19. Close the attribute table of 'Water_bodies.shp'. Now you will see in the View that one of the polygons is coloured yellow. This is the polygon that you selected in the attributes table. So now you know the number of the polygon, and you know which polygon in the View is connected to that record. The name of the waterbody is shown in the 'Pais_pesca_Biodiv_floodplain.tiff' Image.
20. Determine the Names of all waterbodies, and add them to the Attributes of Water_bodies.shp table.

After making this Theme, containing polygons representing waterbodies, another Theme to be made could be a Theme showing the positions of the roads. What would be the feature type of this Theme?[45]

1. Open the View of your current project.
2. Go via the menu bar to **View/New Theme....** In the dialogue box select 'Line' as the Feature type from the drop-down menu and press **OK**.

[45] In this case the most appropriate feature type would be 'Line'.

3. Save the New Theme with the filename: 'road.shp' in the dialogue box that pops up. Make sure you save it in the appropriate folder and on the appropriate drive.

The 'road.shp' Theme is added to the map legend, with the dashed line round its checkbox indicating that the Theme is editable. Go to the Legend Editor (menu bar: **Theme/Edit Legend...**) and change the Symbol in such a way that it will be clearly visible (change the colour into purple, and width to 2).

4. From the Drawing tool button drop-down list select the Draw Line tool button.
5. Choose a road in the Image you want to digitize, and follow the same procedure as you have followed digitizing a polygon; Click along the length of the road, until you have reach the end of the road, end the line by double-clicking. Select the line tool again and digitize the next part of the roads, etc.

After you have digitized all roads that you wanted to digitize, save your work: Via the menu bar go to: **Theme/Stop Editing**. Click **Yes** to save edits.

The line that you worked on last is highlighted (with yellow). Click the Clear Selected Features tool button to deselect it.

After a polygon Theme, and a line Theme, you will make in the following exercise a point Theme. This type of Theme is the ideal way to store data, if you have made specific measurements on a specific location. For this exercise you will digitize the locations of the sampling stations on the 'Pais_pesca_Biodiv_floodplain.tif' Image.

6. Open the View of your current project.
7. Go via the menu bar to **View/New Theme...**. In the dialogue box select 'Point' as the Feature type from the drop-down menu and press **OK**.
8. Save the New Theme with the filename: 'Sampling_stations.shp' in the dialogue box that pops up. Make sure you save it in the appropriate folder and on the appropriate drive.

The 'Sampling_stations.shp' Theme is added to the map legend, with the dashed line round its checkbox indicating that the Theme is editable.

9. From the Drawing tool button drop-down list select the Draw Point tool button.
10. Zoom in on the sampling station you want to digitize (sampling stations are indicated by a red circle with a red cross). After you have zoomed in on the sampling station, and made sure you have pressed the Draw Polygon button, move the pointer to the centre of the sampling station, and click it with your mouse. After having selected one sampling station, go to the next and select if following this procedure.
11. When you have added all sampling stations you can finish editing the new Theme; go via the menu bar to **Theme/Stop Editing**. Press **Yes** to save the edits.

After these exercises you know how to register an image of which at least two locations are georeferenced, and you can use this image to make three types of Themes (polygon, line, and point Themes). Previously (Putting field data into a GIS, page 36) you have learned how to add data to existing Themes, which you practised in these exercises as well.

18.1.3 Real world exercise, Rio Uneiuxi, Brazil

If you want to get some more experience registering, then try to register the map of the Rio Uneixu[46] in Brazil.

1. Start ArcView, Open a new View;
2. Set the working directory;
3. Set the projection (Category: Projections of the World, Type: Geographic); and
4. Add the image 'Rio_Uneiuxi.tif' located in the folder 'RW_06_Brasil_Geo'.

FIGURE 18.16
Image of Rio Uneiux with georeferenced points

You will see the scan of a map of an area in the north of Brazil. Unfortunately, the latitudes and longitudes of the lines you see in the image, which are normally written on the map, are not known. The only data that came with this map is that one point in the red squares (Figure 18.16) has the values: X: -65.06941 and Y:-0.72384, while the

[46] Courtesy of Paulo Petry Bio-Amazonia Conservation Intl. Projeto Radam, Brasil, Carta Imagem Radar, Santa Isabel do Rio Negro SA.20-V-A, MIR-56 1:250 000, Ministério do Exercito - Depto. de Engenharia e Comunicações, Diretoria de Serviço Geográfico 5a DL Brasilia, DF. published in 1984.

other point the following data contains: Latitude: 0°27'4" (S), Longitude: 65°15'9" (W) (The letters S and W mean south and west).

Recalculate the obvious DMS values of the second point into decimal degrees. Pay special attention to the fact that the points are south of the Equator, and west of the Greenwich Meridian[47].

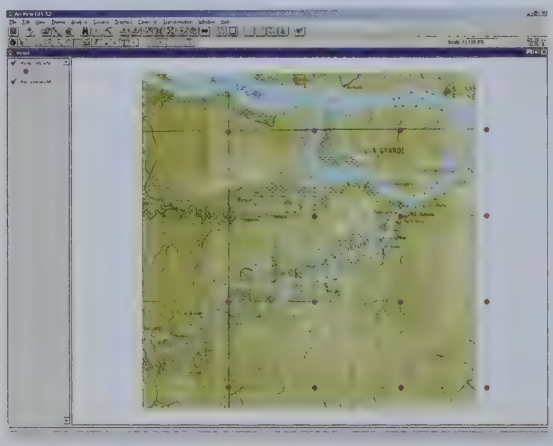
Determine which values belong to which point, keep in mind the fact that the points are south of the Equator, and west of the Greenwich Meridian[48].

5. With the (calculated) values of both points, register the image, using these points, in ArcView.

Check this registration: Add the Theme 'Geopoints.shp' from the folder: 'RW_06_Brasil_Geo' to the View. If you have done everything correctly, you will see that the points will be on the crossings of the Latitude and Longitude lines, except for four points which will be outside the area of the image.

You can also add the Theme: 'Large rivers of the world.shp' from the same folder. You will see that rivers from this Theme do not correspond precisely with the rivers in the Image you have registered, but come very close. Over time rivers may change their courses, which we see here (Figure 18.17).

FIGURE 18.17
The Attributes table with a record selected



In the folder 'RW_06_Brasil_Geo' you will find the file 'Villages.xls'. This file contains the locations and names of the villages on the map. You can use this file to make a point Theme on the map you have just registered. Try to do this, as is explained from page 36, Putting field data into a GIS, and keep in mind that all points are west of the Greenwich Meridian, and south of the Equator, meaning that both the X's and Y's will have negative values. If you want to check the outcomes of your calculations, check the file 'Solution_Villages.xls' in the folder 'RW_06_Brasil_Geo'.

[47] both X and Y values will be negative!!!!

[48] Point 1: Latitude: 0°27'4"(W), Longitude: 65°15'9"(S) (=X: -65.2525, Y: -0.451111), Point 2: X:65.06941, Y: -0.72384.

Bibliography

COPEMED. 2001a. *Towards the use of Geographic Information Systems as a decision support tool for the management of Mediterranean fisheries*, by A. Bensch & M. Taconet. Informes y Estudios COPEMED No. 4. (available at: http://www.faocopemed.org/vldocs/0000028/index.htm).

COPEMED. 2001b. *GIS in fisheries management, Training manual, Higher national diploma in fisheries science for the Mediterranean countries*. Rome, Italy, Department of fisheries and aquaculture (Malta), University of Plymouth (UK) and COPEMED (FAO). 135 pp.

Corsi, F. 2000a. Geographical information systems and surplus production models: a new model for spatial assessment of demersal resources. *In* M. Taconet & A. Bensch, eds. *Towards the Use of Geographic Information Systems as a Decision Support Tool for the Management of Mediterranean Fisheries*. Informes y Estudios COPEMED No. 4. (available at: http://www.faocopemed.org/vldocs/0000028/publi07.pdf).

Corsi, F. 2000b. Spatial distribution of fishing effort: modelisation through deductive methodologie. *In* M. Taconet & A. Bensch, eds. *Towards the Use of Geographic Information Systems as a Decision Support Tool for the Management of Mediterranean Fisheries*. Informes y Estudios COPEMED No. 4. (available at: http://www.faocopemed.org/vldocs/0000028/publi06.pdf).

Corsi, F., Agnesi, S. & Ardizzone, G. 2001. Integrating GIS and surplus production models: a new approach for spatial assessment of demersal resources? *In* T.Nishida, P.J. Kailola & C.E. Hollingworth, eds. *Proceedings of the First International Symposium on Geographic Information Systems (GIS) in Fishery Science*. Seattle, Washington, USA, 2–4 March 1999, Fishery GIS Research Group.

ESRI. 2001. *The ESRI Press dictionary of GIS terminology*. Redlands, California, Environmental Systems Research Institute, Inc. 116 pp. (available at: http://www.evansvillegis.com/PDF/GIS_Dictionary.pdf).

FAO. 1987a. *A geographical information system to plan for aquaculture development: a FAO - UNEP/GRID study in Costa Rica*, by J.M. Kapetsky, L. McGregor & E.H. Nanne. FAO Fisheries Technical Paper No. 287. Rome. 51 pp.

FAO. 1987b. *Satellite remote sensing to locate and inventory small water bodies for fisheries management and aquaculture development in Zimbabwe*, by J.M. Kapetsky. FAO CIFA Occasional Paper, 14: 1–11.

FAO. 1989a. *A geographical information system for aquaculture development in Johor State*, by J.M. Kapetsky. FAO Technical Cooperation Programme Project. Land and Water Use Planning for Aquaculture Development. TCP/MAL/6754. Field Document. Rome. (available at: http://www.fao.org/docrep/field/003/T5057E/T5057E00.htm).

FAO. 1989b. Report of the FAO Asian Regional workshop on geographical information systems applications in aquaculture. Bangkok, Thailand, 5–23 December 1988. FAO Fisheries Report, 414: 1–13.

FAO. 1990. *Use of geographic information system (GIS) to select priority for fish farm development*, by J.M. Kapetsky & N. MacPherson. FAO Technical Cooperation Programme Project. Technical Assistance and Investment Framework for Aquaculture in Ghana. FI:TCP/GHA/0051. Field Document. Field Working Paper No. 9. Rome.

FAO. 1991a. *Geographical information systems and remote sensing in inland fisheries and aquaculture*, by G.J. Meaden & J.M. Kapetsky. FAO Fisheries Technical Paper No. 318. Rome. 262 pp. (available at: http://www.fao.org/DOCREP/003/T0446E/T0446E00.HTM).

FAO. 1991b. Report of the FAO Africa Region workshop on applications of geographical information systems and remote sensing in aquaculture and inland fisheries in cooperation with UNEP/GRID. FAO Fisheries Report, 451: 1–35.

FAO. 1991c. *Where are the best opportunities for fish farming in Ghana? The Ghana aquaculture geographical information system as a decision-making tool*, by J.M. Kapetsky, U.N. Wijkstrom, N. MacPherson, M.M.J. Vincke, E. Ataman & F. Caponera. FAO Technical Cooperation Programme Project. Technical Assistance and Investment Framework for Aquaculture in Ghana. FI:TCP/GHA/0051. Field Document. Field Technical Paper No. 5, Rome. (available at: http://www.fao.org/docrep/field/003/AC106E/AC106E00.htm).

FAO. 1992. Workshop on applications of geographical information systems (GIS) and remote sensing applied to aquaculture and inland fisheries in Africa. FAO Rapport sur les Peches No. 466. Rome.

FAO. 1996. *Geographical information systems. Applications to marine fisheries*, by G.J. Meaden & Do Chi. FAO Fisheries Technical Paper No. 356. Rome. 335 pp. (available at: http://www.fao.org/DOCREP/003/W0615E/W0615E00.HTM).

FAO. 1997a. *A strategic assessment of the potential for freshwater farming in Latin America*, by J.M. Kapetsky & S.S. Nath. FAO COPESCAL Technical Paper No. 10. Rome. 128 pp. (available at: http://www.fao.org/DOCREP/005/W5268E/W5268E00.HTM).

FAO. 1997b. *Catch and fish stock assessment in stratum VII of Lake Volta. Integrated Development of Artisanal Fisheries (IDAF)* by G.J. de Graaf & P.K. Ofori-Danson. GHA/93/008. IDAF Technical Report/97/1. Rome. (available at: http://www.nefisco.org/downloads/Lake%20volta%20final%20report.PDF).

FAO. 1998a. *A strategic assessment of the potential for freshwater fish farming in the Caribbean Island States*, by J.M. Kapetsky & B. Chakalall. FAO COPESCAL Technical Paper No. 10 Supplement. Rome. 41 pp. (available at: http://www.fao.org/DOCREP/005/X0332B/X0332B00.HTM).

FAO. 1998b. *A strategic reassessment of fish farming potential in Africa*, by J. Aguilar-Manjarrez & S.S. Nath. FAO CIFA Technical Paper No. 32. 170 pp. (available at: http://www.fao.org/docrep/W8522E/W8522E00.htm).

FAO. 1998c. Geography and constraints on inland fishery enhancements, by J.M. Kapetsky. *In* T. Petr, ed. *Inland fishery enhancements*, pp. 37–63. FAO Fisheries Technical Paper No. 374. Rome. 463 pp. (available at: http://gilws05/docreptest/FAO/005/W8514E/W8514E00.HTM).

FAO. 1999a. *Inventory and monitoring of shrimp ponds in Sri Lanka by ERS SAR data*, by C. Travaglia, J.M. Kapetsky & G. Profeti. Environmental and Natural Resources Service. Sustainable Development Department. FAO Environment and Natural Resources Working Paper No. 1. Rome. 34 pp. (available at: http://www.fao.org/sd/eidirect/EIan0012.htm).

FAO. 1999b. *Zoning for coastal aquaculture*, by G.J. Meaden. FAO Technical Cooperation Programme Project. Revitalization and Acceleration of Aquaculture Development. TCP/SRL/6715. Field Document. FAO, Bangkok, Thailand.

FAO. 2000. FAO Fisheries Department, Data and Statistics Unit. FISHSTAT Plus: Universal software for fishery statistical time series. Version 2.3.

Fox, W.W. Jr. 1970. An exponential surplus-yield model for optimizing exploited fish populations. *Trans. A. Fish. Soc.*, 99: 80–88.

de Graaf, G.J. & Xuan, T.T. 1998. Extensive shrimp farming, mangrove clearance and marine fisheries in the southern provinces of Vietnam. *Mangroves and Salt Marshes*, 2: 159–166. (available at: http://www.nefisco.org/publications.htm).

de Graaf, G.J., Khan, M.G., Faruk, O., Lubna, Y. & Mamun, A. 2000. *FISH-GIS,An Introduction to the use of Geographical Information Systems and Remote sensing in Fisheries Monitoring, Analysis and Management. A training Manual.* EGIS Publication 2000-1. Dhaka, EGIS, 181 pp. (available at: http://www.nefisco.org/downloads/Fish_GIS_Bangladesh.pdf).

de Graaf, G.J., Born, B., Uddin, K.A. & Marttin, F. 2001. *Floods, Fish & Fishers. Eight years experience with floodplain fisheries, fish migration, fisheries modelling and fish biodiversity in the compartmentalization pilot project*, Bangladesh. The University Press Limited, Dhaka, 108 pp. (available at: http://www.nefisco.org/publications.htm).

Gulland, J. 1985. Comments and questions on ecosystem management. Selected papers presented to the scientific committee of CCAMLR, 1982–1984, part 2.

Hilborn, R. & Walters, C.J. 1992. *Quantitative fisheries stock assessment. Choice, dynamics and uncertainty*. New York, USA, Chapman and Hall.

Junk, W.B., Bayley, P.B. & Sparks, R.E. 1989. The floodpulse in river floodplain systems. *In* Proceedings of the International Large River Symposium. D.P. Dodge, ed. *Can. Spec. Publ. Fish. Aquat. Sci.*, 106: 110–127.

Kapetsky, J.M. 1994a. The potential for warm water fish farming in the SADC countries. *FAO Aquaculture Newsletter*, 6: 2–6.

Kapetsky, J.M. 1994b. The potential for warm water fish farming in Africa. A strategic assessment from a continental viewpoint. *In* P. Kestemont, J. Muir, F. Sevila & P. Wilmot, eds. *Measures for success. Meteorology and instrumentation in aquaculture management*, pp. 67–73. CEMAGREF Editions.

Kapetsky, J.M. 1995. A first look at the potential contribution of warm water fish farming to food security in Africa. *In* J.-J. Symoens & J.C. Micha, eds. *Proceedings of the seminar on the management of integrated freshwater agro-piscicultural ecosystems in tropical areas*. pp. 547–572. Wageningen, the Netherlands, CTA.

Kapetsky, J.M. 2001. Recent applications of GIS in inland fisheries. *In* T. Nishida, P.J. Kailola & C.E. Hollingworth, eds. *Proceedings of the first international symposium on GIS in fishery science*, pp. 339–359. Seattle, Washington, 2–4 March 1999. Fishery GIS Research Group, Saitama, Japan.

Munro, J.L. & Thompson, R. 1983a. Areas investigated, objectives and methodology. *ICLARM Stud. Rev.*, 7: 15–25.

Munro. J.L. & Thompson, R.. 1983b. The Jamaican fishing Industry. *ICLARM Stud. Rev.*, 7: 15–25.

Mustafa, Md. G. & Khan, Md. G. 1993. The bottom trawl fishery, BOBP/WP/89.

Nishida, T., Kailola, P.J. & Hollingworth, C.E. 2001. *Proceedings of the First International Symposium on Geographic Information Systems (GIS) in Fishery Science*. Seattle, Washington, USA, 2–4 March, 1999. Fishery GIS Research Group. Japan. 486 pp. (available at: http://www.esl.co.jp/Sympo/1st/sympo.htm).

Nishida,T., Kailola, P.J. & Hollingworth, C.E. (In Press). *Proceedings of the Second International Symposium on GIS in Fisheries and Spatial Analyses*, University of Sussex, England. September 3–6, 2002. Fishery GIS Research Group. Japan. (available at: http://www.esl.co.jp/Sympo/2nd/sympo10.htm).

Pitcher, T.J., & Hart, P.J.B. 1982. *Fisheries ecology*. London, UK, Croom Helm.

Quin, T.J. & Deriso, R.B. 1999. *Quantitative Fish dynamics*. Oxford University Press, Oxford. 542 pp.

Schaefer, M. 1954. Some aspects of the dynamics of populations are important to the management of the commercial marine fisheries. *Bull. 1-ATTC/Bol.CIAT*. 1(2): 27–56.

Travaglia, C. & Appelkamp, C. 1985. *Applications of Remote Sensing to Aquaculture and inland fisheries*. Ninth UN/FAO International Training Course in Cooperation with the Government of Italy. Rome, Italy, 10–28 September 1984. RSC SER., No. 27, FAO, 301 pp.

Valavanis, V.D. 2002. *Geographic Information Systems in Oceanography and Fisheries*. London, Taylor & Francis. 209 pp.

Annex A: Pais Pesca

Introduction
Pais Pesca was founded on October 16, 1945 after a peaceful struggle against a foreign ruler. The country was named Pais Pesca, because of the vast abundance of fisheries resources (be it inland or marine) and the importance of these resources for the population (Figure A.1).

Geography
The country is situated a few degrees north of the equator. In the northeast it is bordered by the Republic of Bodor, in the northwest by the Federal State of Kadini and its southern border is made up by the Sea of Bodor (Figure A.2).

FIGURE A.1
The Pais Pesca flag

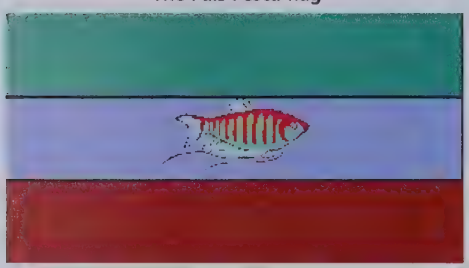
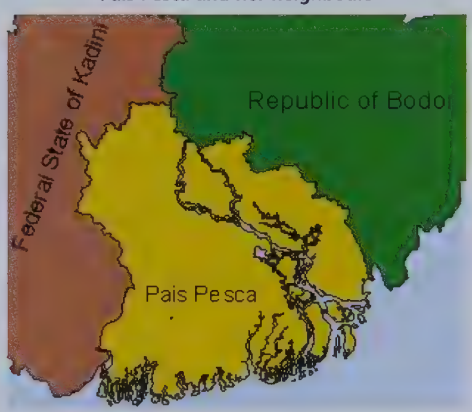


FIGURE A.2
Pais Pesca and her neighbours



Pais Pesca has a tropical climate. Three distinct seasons can be distinguished: A mild winter from October to March followed by a hot, humid summer (March to June), after which the humid, warm rainy monsoon from June to October forms the third season. Maximum temperatures range between 25–35 °C and the minimum temperature is about 10 °C. The lower temperatures tend to occur in the north and east. Rainfall ranges from 1 400 mm to 3 500 mm on average annually. The monsoon brings the majority of the rains during five months from the end of May to about mid-October. These rains and the resulting flooding of the low lying floodplains are a major driving force behind agriculture practices and inland fisheries in Pais Pesca.

Topography
The lowest point of Pais Pesca is at the Sea of Bodor, at 0 metres, while the highest point is in the northwest at 650 metres (Figure A.3). The natural resources of Pais Pesca are gas, coal, arable land, and, of course, water resources.

The country is prone to several natural dangers: inundation during the summer monsoon season, drought during the winter season, and cyclones during the start of the monsoon season.

Population
The total population consists of approximately 23 millions people (1999 est.). Seventy four percent of these people live in rural areas. Population is not distributed equally throughout the country. Densities are between 527 people per square kilometre (Tara district) and 83 people per square kilometre (Pepedas district).

Economy

Despite sustained domestic and international efforts to improve economic and demographic prospects, Pais Pesca remains one of the worlds poorest, most densely populated, and least developed nations. Although more than half of GDP is generated through the service sector, nearly two-thirds of Pescans are employed in the agriculture sector, with rice as the single most important product. The main export products are garments, jute and jute goods, leather, frozen fish and seafood (Figure A.4).

FIGURE A.3
Elevation map of Pais Pesca

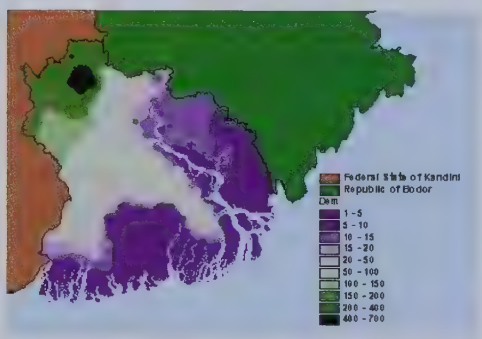
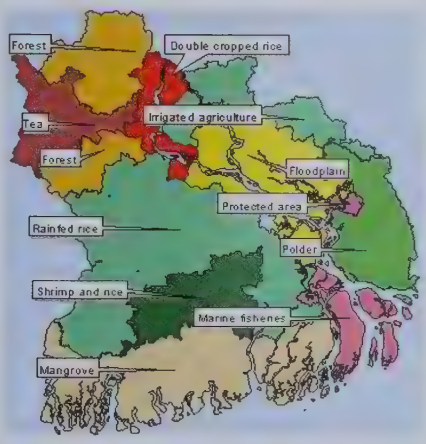


FIGURE A.4
Main land-use in Pais Pesca



Major impediments to growth include frequent cyclones and floods, inefficient state-owned enterprises, inadequate port facilities, a rapidly growing labour force that cannot be absorbed by agriculture, delays in exploiting energy resources (natural gas), insufficient power supplies, and slow implementation of economic reforms.

Agriculture

The Pescan agriculture consists mainly of large-scale subsistence farming, which is labour intensive and heavily dependent on monsoon rains. The main crops are rice, jute, wheat, and tea, while forestry products, sugarcane, potatoes, tobacco, pulses, oilseeds, spices, fruit beef, milk, and poultry form also an important part of the agricultural production.

Fisheries

Fourty percent of fisheries production in Pais Pesca is produced by aquaculture. Aquaculture has a long tradition in Pais Pesca. Lately the Department of Fisheries has tried to increase the production of aquaculture farms by propagating modern techniques, which would result in a doubling of aquaculture production. The last ten years shrimp farming gained in popularity, because of its high returns. In 1999 only 13 percent of the aquaculture volume consisted of shrimps, while the value of these shrimps made up 26 percent of the total aquaculture production value.

Besides aquaculture, inland capture fisheries are important for the Pescans. It forms 38 percent of the total fisheries production. This number can be an underestimation, because, like in many developing countries, statistics on inland capture fisheries form a problem. Inland capture fisheries form an important source of protein for the poorest segment of the Pescan population. Like most other floodplain fisheries the Pescan floodplain fisheries are very productive in the period when the floods are receding (October to January).

Marine fisheries form 22 percent of the total fisheries production. Because of the preference of the Pescans for freshwater fish, most of the marine production is being exported.

Forestry

The hills in the northwest of the country are covered by dense forests from which the local population extracts fire wood. The larger timber is of high quality and is being exported.

Annex B: ArcView and Microsoft Excel

In ArcView there are a few ways to work with Microsoft Excel spreadsheet data:

- Editing an existing ArcView '.dbf' file in Microsoft Excel;
- Creating a new table in Microsoft Excel and then importing it into ArcView;
- Using ArcViews SQL connection feature to retrieve records from an existing Microsoft Excel spreadsheet.

Editing an existing ArcView '.dbf' file in Microsoft Excel

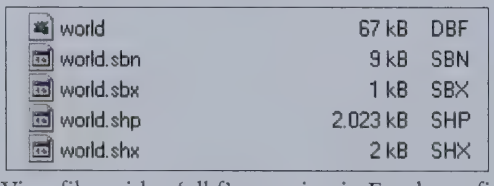
A Theme consists of several files (Figure B.1), mostly files with the extensions '.sbn', '.sbx', '.shp', '.shx', and '.dbf'. If you want to put a Theme on a floppy disk, you have to copy all files to be able to display the Theme on another PC.

ArcView shapefiles are a simple, non-topological format for storing the geometric location and attribute information of geographic features. A shapefile is one of the spatial data formats that you can work with in ArcView.

The shapefile format defines the geometry and attributes of geographically-referenced features in as many as five files with specific file extensions that should be stored in the same project workspace. They are:

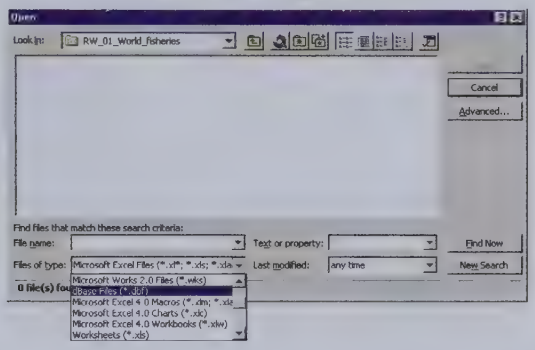
- '.shp' – the file that stores the feature geometry.
- '.shx' – the file that stores the index of the feature geometry.
- '.dbf' – the dBASE file that stores the attribute information of features. When a shapefile is added as a theme to a view, this file is displayed as a feature table.
- '.sbn' and '.sbx' – the files that store the spatial index of the features. These two files may not exist until you perform theme on theme selection, spatial join, or create an index on a theme's Shape field. If you have write access to the source data directory, the index files will be persistent and remain after your ArcView session is complete. If you do not have write access to the source data directory, they will be removed when you close the project or exit ArcView.
- '.ain' and '.aih' – the files that store the attribute index of the active fields in a table or a theme's attribute table. These two files may not exist until you perform Link on the tables. If you have write access to the source data directory, the index files will be persistent and remain after your ArcView session is complete. If you do not have write access to the source data directory, they will be removed when you close the project or exit ArcView.

FIGURE B.1
The different files making a shapefile in ArcView



To edit the ArcView files with a '.dbf' extension in Excel you first need to import the file into Excel by using (in Excel) **File/Open...** via the menu bar. At the bottom of the **Open** window (which will pop up) is a drop down list (Figure B.2) for **Files of type**: Select dBase Files (*.dbf) from the drop-down list, and open your file.

FIGURE B.2
The Open File dropdown list

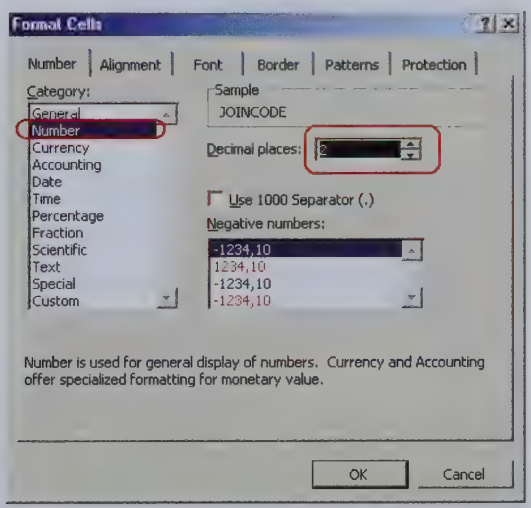


While using Excel, you can make changes to the data, add fields, perform calculations, etc., in the spreadsheet. However, if you simply save the changed file as a '.dbf' file (still using Excel) and then try to open it in ArcView, none of the changes you made will appear in ArcView.

To get around this problem is easy. When you have finished making changes to your file in Excel copy all columns and rows in your file (whether changed or unchanged) that have data in them and paste them into a new, empty spreadsheet in Excel.

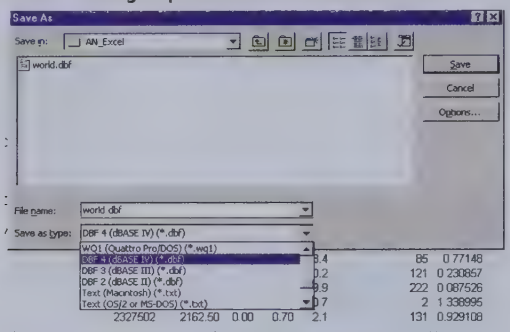
When you copy these cells DO NOT copy them by selecting the entire worksheet for copying; but select only those cells that have data in them. If the spreadsheet contains columns with decimal data, then first format the columns and indicate the number of decimals (Figure B.3). This is of utmost importance if your spreadsheet contains X and Y-coordinates in longitude and latitude.

FIGURE B.3
Formatting your cells in Excel

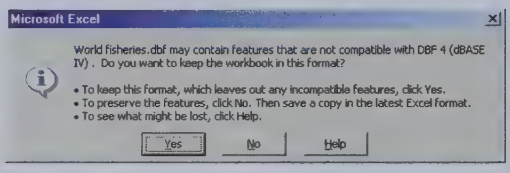


Before saving the new spreadsheet in Excel, be sure to click on one of the cells with data in it, so that it is highlighted. When ready to save the new spreadsheet in Excel, select **File/Save As...** via the menu bar. The Save As window will pop-up. Give the new spreadsheet a name (If you are editing a .dbf file of an existing ArcView Theme, then give it here the exact name of the original file). Make sure that it has a '.dbf' extension by selecting from the dropdown list for 'Save as type' 'DBF 4' (dBase IV) (*.dbf)' (Figure B.4).

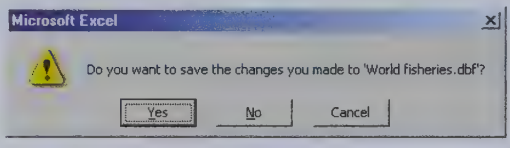
FIGURE B.4
Saving a spreadsheet as a .dbf file in Excel



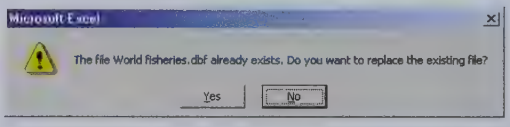
When you click the **Save** button the following window will pop-up.


Microsoft Excel
World fisheries.dbf may contain features that are not compatible with DBF 4 (dBASE IV). Do you want to keep the workbook in this format?
• To keep this format, which leaves out any incompatible features, click Yes.
• To preserve the features, click No. Then save a copy in the latest Excel format.
• To see what might be lost, click Help.
Yes
No
Help

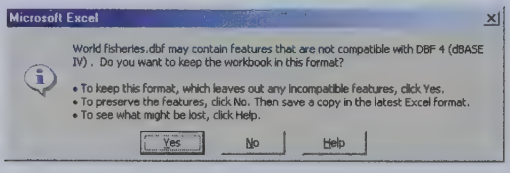
Click **Yes**. When you close the spreadsheet you will get the following message:



Click **Yes.** The following message will pop up:



Click **Yes**. The last message pops up:


Microsoft Excel
World fisheries.dbf may contain features that are not compatible with DBF 4 (dBASE IV). Do you want to keep the workbook in this format?
• To keep this format, which leaves out any incompatible features, click Yes.
• To preserve the features, click No. Then save a copy in the latest Excel format.
• To see what might be lost, click Help.
Yes
No
Help

Click **Yes**.

It seems complicated but it really works. Now you have saved the file and you can open and use it in ArcView.

Try to apply this method. On the CD in the folder 'AN_Excel' you can find the same world Theme you have used in the real world exercise world fisheries. Try to import the file 'world.dbf' into Excel, calculate population per hectare (take care that you need to multiply Pop_95 with 1 000 first!). and after that export this file as a .dbf file (as world.dbf). Start ArcView, Open a New Theme, and add the Theme 'world.shp'. Look at the Attribute Table of world.shp, and you will see that the changes you made do not appear. Now use the method described above, taking care that if you have a calculation in a column, you need to copy this column and use **Edit/Paste Special..., Values**.

Creating a new table using Microsoft Excel and importing it into ArcView

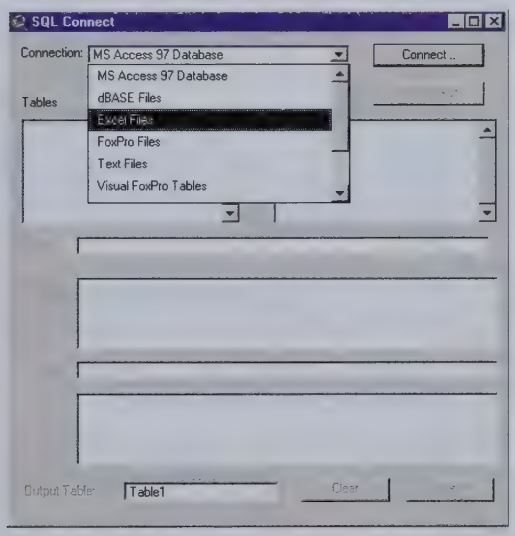
Another method using Microsoft Excel, is to create an entirely new spreadsheet that can be incorporated into ArcView. The key here is to have one column in your Excel file that matches exactly a pre-existing column in the ArcView .dbf file that is associated with the Theme that you are working on so that you can join the two. Saving this spreadsheet in Excel in a .dbf format follows the procedures as given above.

Using the SQL connection in ArcView

The use of the SQL connection to import a Microsoft Excel spreadsheet directly into ArcView will be explained with the example of the Three districts in Pais Pesca as given in the chapter Joining a table with a polygon file on page 24. In this example you added the file with the data by importing the '.dbf' file, which you joined then with the Theme. The data for the three districts are also available in an Excel spreadsheet. You will be shown how to import these data directly into ArcView.

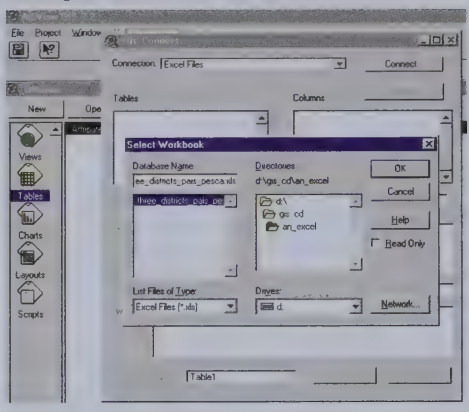
1. Start ArcView, Open a New Project, and Open a New View. Add the Themes 'Pais_pesca_country.shp' and 'Three_districts_pais_pesca.shp' (from the 'AN_Excel' folder on your CD) to the View.
2. Open the Attribute Table of the 'Three_districts_pais_pesca.shp' Theme and you will see that it contains the 'Shape', 'Subd_code', and 'Subd_name' fields. You will have to join the data in the Excel file 'Three_districts_pais_pesca.xls' with this attribute table.
3. Close the View and go via the menu bar to **Project/SQL Connect...**
4. The SQL Connect window will appear and in the Connection drop down list you need to select 'Excel Files' (Figure B.5).

FIGURE B.5
The SQL Connect window



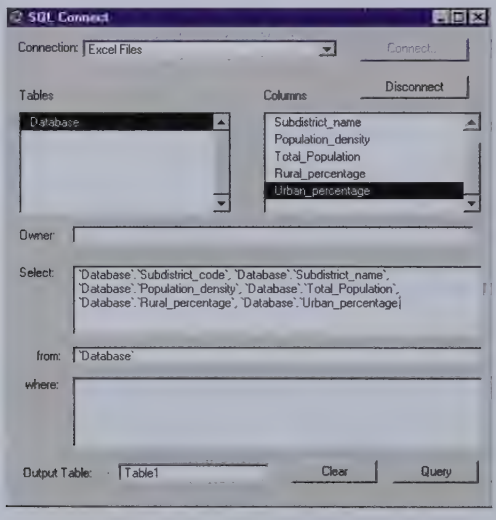
5. Click **Connect**, after which the **Select Workbook** window will popup (Figure B.6). Go to the correct drive and the correct folder ('AN_Excel' on your CD), and select the file 'Three_districts_Pais_Pesca.xls', click **OK.**

FIGURE B.6
Selecting the correct Excel file for the SQL connection



6. You will come back in the **SQL Connect** window. Double-click on 'Database' in the **Table** box. In the **Columns** box all column headings of the selected spreadsheet will appear.
7. Select (by Double clicking the Column names) the names of the columns you want to import (For this exercise import the following Columns: Subd_code, Subd_name, Population, Total_pop, Rural_perc, and Urban_perc). The selected Columns will appear in the Select box. Give the table a name (in the Output Table: box) and click on **Query** (Figure B.7).
8. The generated table will open in ArcView. Join the generated table with the Theme using the same method as in the chapter Joining a table with a polygon file on page 24.

FIGURE B.7
Making a table from Excel data using SQL



Annex C: Kriging

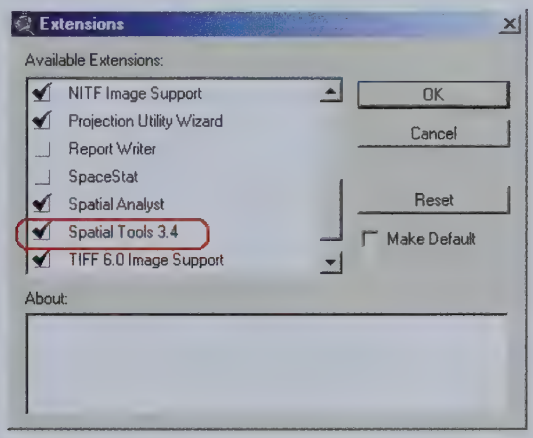
Installing Kriging Scripts

Kriging interpolation of data is a regular part of the Spatial Analyst software, however, to use this you need to be able to program in Avenue, the programming language of ArcView. Fortunately there are several free scripts for Kriging available on the Internet. An example of such a tool is the Spatial Tools ArcView extension that can be downloaded from (among others): http://www.absc.usgs.gov/glba/gistools/. You can find the file and its documentation in the folder /extensions/kriging on the CD. In order to be able to use this add-in you have to:

1. Copy the 'g2i.dll' file from the '/extensions/kriging' on the CD to the ArcView Bin32 folder (the path will look like the following, although the drive letter may not be the same, and also you might be using a different version of ArcView): C:\ESRI\AV_GIS30\ARCVIEW\BIN32.
2. Copy the 'Spatiatools.avx' file to the ArcView Ext32 directory (The same comment as made above applies here): C:\ESRI\AV_GIS30\ARCVIEW\EXT32.

After you have opened ArcView, Go to **File/Extensions...** via the menu bar and select Spatial Tools 3.4 (Spatial Analyst needs to be selected first) (Figure C.1).

FIGURE C.1
Making the Spatial Tools extension active in ArcView



What is Kriging[49]

Kriging is a powerfull statistical interpolation method. The technique was co-developed by Georges Matheron (a French geomathematician) and D.G. Krige (a South African mining engineer) to analyse geochemical data to find gold deposites (and it worked!). The difference between ordinary interpolation in ArcView and Kriging is that with Kriging an initial structural spatial analysis is carried out, looking at the variance and autocorrelation of the data. The results of the analysis are then used to select the interpolation model and carry out the interpolation. Kriging is an estimation method that is associated with the acronym BLUE (Best Linear Unbiased

[49] Adapted from:
http://www.nbb.cornell.edu/neurobio/land/OldStudentProjects/cs490-94to95/clang/kriging.html.

Estimator). It is linear since the estimated values are weighted linear combinations of available data. It is unbiased because the mean of the error is zero. It is best since it aims at minimizing the variance of the errors. Therefore the word Kriging is synonymous with optimal prediction.

In Kriging a semivariogram is constructed which expresses the spatial variation in the data. Then the mathematical model of the semivariogram is used in calculating estimates of the surface at the different locations. Kriging will result in two images, a surface of estimates and a surface of estimated variances. The latter image can be used to identify problems with the fit of the model to the sample data by revealing relative differences in the model fit across the study area. For a more detailed explanation you can visit: http://www.nbb.cornell.edu/neurobio/land/OldStudentProjects/cs490-94to95/clang/kriging.html.

Semivariogram

Semi variance is a measure of the degree of spatial dependence between samples. The magnitude of the semi variance between points depends on the distance between the points. A smaller distance yields a smaller semi variance and a larger distance results in a larger semi variance. Given two locations **x** and **(x+h)**, a measure of one half of the mean square difference (the semivariance) produced by assigning the values **z(x+h)** to the value **z(x)**, where **h** (known as the lag) is the inter-sample distance. Plotting the semivariance versus the lag **h** gives a semivariogram. Mathematically the semivariance is written as:

$$\gamma^*(h) = \frac{1}{2n}\sum_{i=1}^{n}\left(z(x_i) - z(x_i+h)\right)^2$$

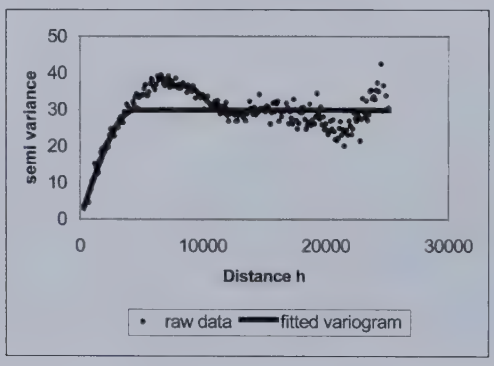
where:

$\gamma^*(h)$	is the calculated value of the variogramme or covariance at a distance h.
Z	is the attribute value.
N	is the number of pairs of sample points separated by h.

The summation is carried out over all distances h.

The plot of the semi variance as a function of distance from a point is referred to as a **semi variogramme (Figure C.2)**. The semi variance increases as the distance increases until it reaches a maximum at a certain distant away from a point. Then the semi variance will equal the variance around the average value, and will therefore no longer increase, causing a flat region to occur on the semi variogram, which is called the **sill**.

FIGURE C.2
A semi variogramme



From the point of interest to the distance where the flat region begins is termed the **range of the regionalized variable**. Within this range, locations are spatially autocorrelated to each other, and all known samples contained in this region, also referred to as the **neighbourhood**, must be considered when estimating the unknown point of interest. The centre of the neighbourhood is usually the unknown value. In order to determine this, unknown, value, all known values within the neighbourhood are assigned weights using the semivariogram. These weight and known values are then used to calculate the unknown value. The kriged estimates are the best linear unbiased estimates of the surface at the specified locations, provided the surface is stationary and the correct form of the semivariogram has been determined. The Kriging script we use provides two grids:

- The data grid; and
- A grid providing the variance.

A large advantage of Kriging is that with the made variance grid of the interpolation you can evaluate how accurate the estimated values are and provide you with evidence of problems of the fit.

Kriging with Spatial Tools

Spatial tools 3.4 provides two Kriging options:

- **Ordinary Kriging**; this is the most commonly used and the simplest form of Kriging. It assumes that local means are not necessarily closely related to the population mean, and which therefore uses only the samples in the local neighbourhood for the estimate.
- **Universal Kriging**, also known as Kriging with a trend. It is used when a trend or slow change of the average values in the samples exists.

Further, there are five mathematical forms the semivariogram can be made:

- **Spherical**: this calculated the variogramme as a modified quadratic function for which at some distance Ao, pairs of points will no longer be auto correlated and the variogramme reaches an asymptote.
- **Circular**: uses a circular neighbourhood search model with a certain **radius.**
- **Exponential**: the exponential model is similar to the spherical in that it approaches the sill gradually. However, different from the spherical in the rate the sill is approached and in the fact that the model and the sill never actually converge.
- **Gaussian**: the gaussian or hyperbolic model is similar to the exponential but it assumes a gradual rise for the y-intercept.
- **Linear with sill:** this model is similar to the linear model except that at some distance pairs of points will be no longer auto correlated and the variogram will reach an abrupt asymptote.

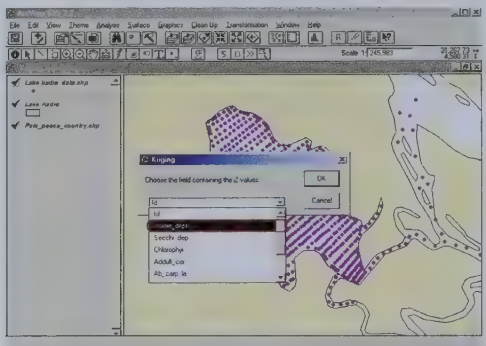
An example of Kriging with data from Pais Pesca

Try to apply Kriging on different data of Lake Kadim in Pais Pesca.

1. Start ArcView, Open a New Project, New View. **Add** the following Themes from the 'AN_Kriging' folder: 'Lake Kadim.shp', 'Lake Kadim data.shp', and 'Pais_pesca_country.shp'.
2. Check the projection and the working directory. Go to **File/Extensions...** and make 'Spatial tools 3.4' active. Activate the 'Lake Kadim data.shp' Theme, and zoom with the 'Zoom to Active Theme(s)' button in the button bar.
3. Now you can start Kriging data of Lake Kadim. First waterdepth data will be kriged.

4. Activate the 'Lake Kadim data.shp' Theme. Go to **Analysis/Kriging Interpolation...** in the menu bar. The Kriging window will pop up and from the drop down list you select 'water_dept' as the field in the table you want to Krig (Figure C.3). Click **OK**.

FIGURE C.3
Selecting the Z-value for Kriging



5. You will be asked if you want to use a barrier to limit the extent of the interpolation. Click **No**, as you have no line barrier (Figure C.4).

FIGURE C.4
Use barrier?

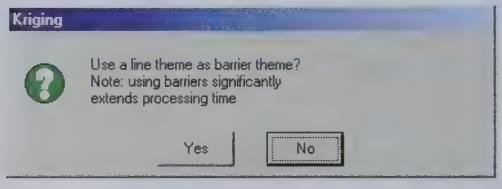
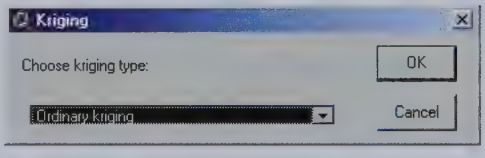
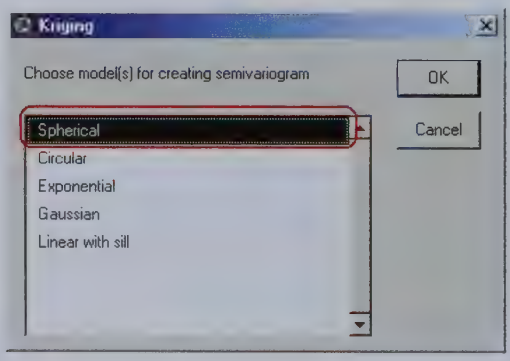


FIGURE C.5
Selecting the type of Kriging



6. A new window pops up where you have to select the type of Kriging. You do not suspect that there is a trend in the water depth data so you select 'Ordinary Kriging' (Figure C.5) and click **OK**.
7. A window will pop up where you have to select what type of model you want to use for the semivariogram. Select 'Spherical' (Figure C.6) and click **OK**.

FIGURE C.6
Selecting the type of model to use for Kriging



8. The **Lag interval window** will pop up. In here you enter the lag interval to calculate the semivariance of the dataset (Figure C.7). This parameter strongly influences the form of the variogram. Further it is impractical to plot a variance for each scatter point with respect of the other scatter points. Therefore the distances are subdivided into a number of intervals called lags (Figure C.8). The distance between each pair of scatter points is checked to see which lag interval it lies in. The variance for all pairs of points whose separation distance falls within the same lag interval is averaged. The resulting average is plotted in the semivariogram versus the distance corresponding to the lag interval. Therefore, there is one point in the variogram for each lag. A small lag interval results in a large number of points in your variogramme, but here each point is the average of a limited number of scatter points. Increasing the lag interval will reduce the number of points in your variogram, but each average is made up of an increasing number of scatter points increasing the accuracy (Figures C.20 and C.21). There are some rules selecting the right number of intervals (Journel and Hubregts, 1978), but you can also get a reasonable guess by looking at the resulting semivariogram. It is a compromise between the accuracy of the calculated semivariance and a sufficient number of data points in the semivariogram to allow reasonable fitting of the curve.

FIGURE C.7
The Lag Interval window

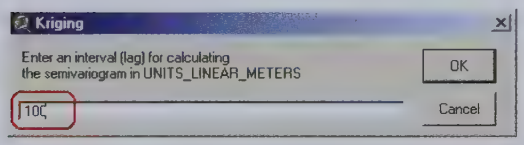
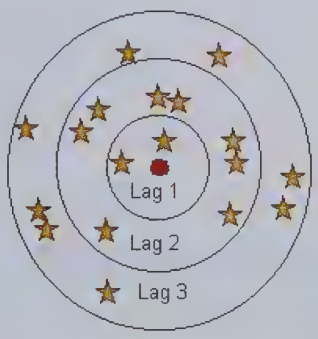


FIGURE C.8
The lag scheme



9. Enter 100 metres as lag interval and click **OK**.
10. The semivariance will be calculated (This may take some time!). After a while a window will appear, saying: 'Write all variogram data to a file? Note: the file svgram1.svg that is added to the project is overwrtitten each time this script is run', indicating that the calculations are made. Click on **Yes**.
11. In the next window you will be asked to indicate the file-type you want to save the data in. Select **dBASE** and click **OK** (Figure C.9).

FIGURE C.9
Saving the result of the kriging as a dBASE file

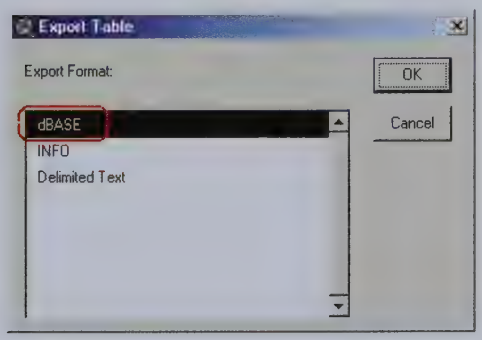
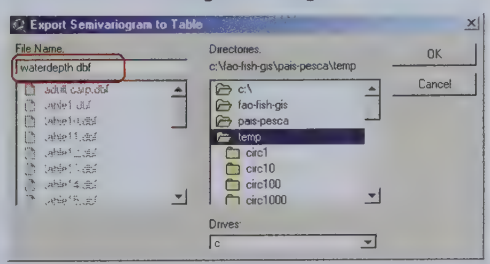


FIGURE C.10
Naming the variogram



12. In the next window provide the name you want to give to the data table (Figure C.10).
13. The next window which pops up (Figure C.11) gives the different codes which are used in the saved table, click **OK**.

FIGURE C.11
Coding of the variogram

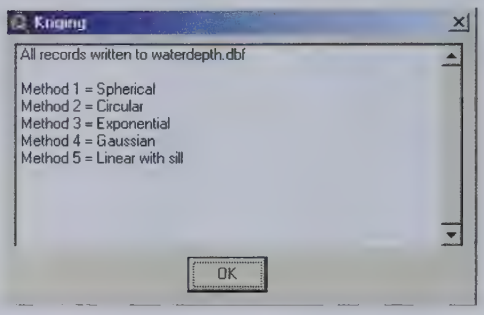
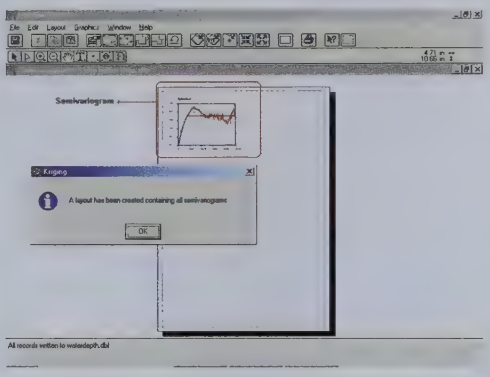


FIGURE C.12
Layout of the generated variogram



14. The created semivariogram appears (Figure C.12). Click **OK**. You will be asked if you want to print out the semivariogram. Make your choice and click the according button.
15. Now you will be asked to start the interpolation (Figure C.13). click **Yes** and select 'Spherical' in the next window (Figure C.14).

FIGURE C.13
Start interpolation?

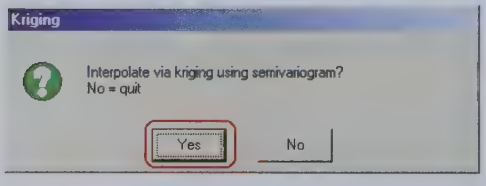
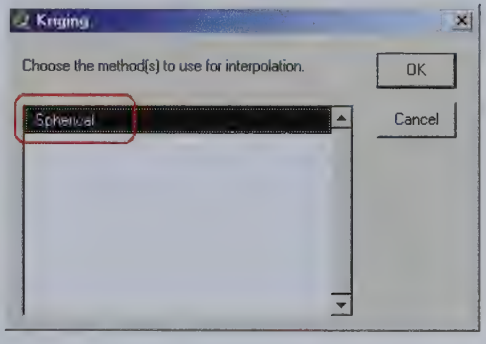


FIGURE C.14
Chosing the method of interpolation



16. An explanation for the next step will appear, read the explanation and click **OK**.

17. In the next window select 'Fixed' from the dropdown box (Figure C.15).

FIGURE C.15
Chosing the type of radius

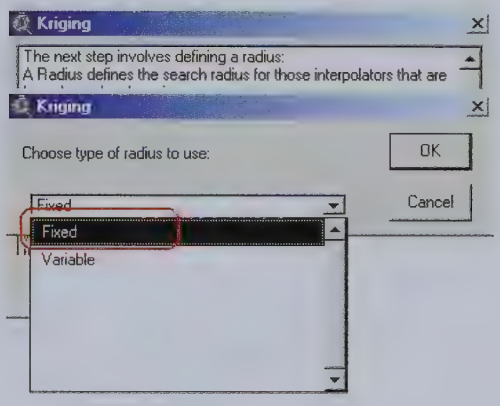
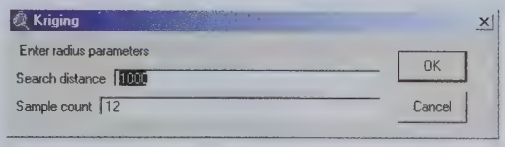
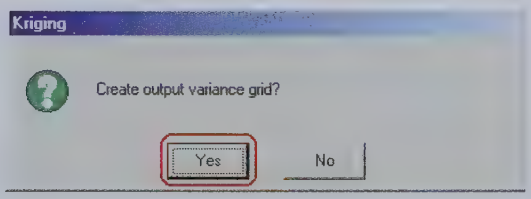


FIGURE C.16
Entering the radius parameters



18. The Output Gird Specification window pops up. Select Same as Display in the Output Grid Extent box, and 100 m for the Output Gird Cell Size.
19. and keep the radius at 1 000 (Figure C.16).
20. The last question is 'Create output variance grid?' (Figure C.17). Click **Yes**.

FIGURE C.17
Creating an output grid?



21. The interpolation will start and both grids will be added to the **View**. Reclassify the legend and you will have the grids as presented in Figure C.18 and Figure C.19

FIGURE C.18
Kriged waterdepth

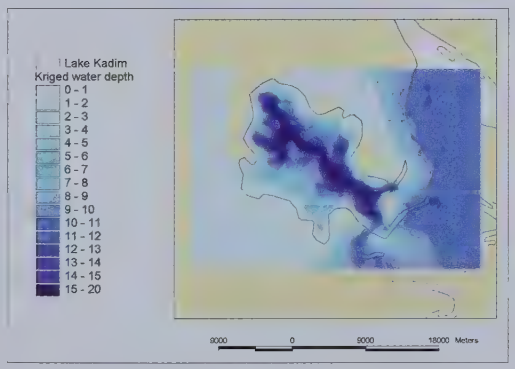
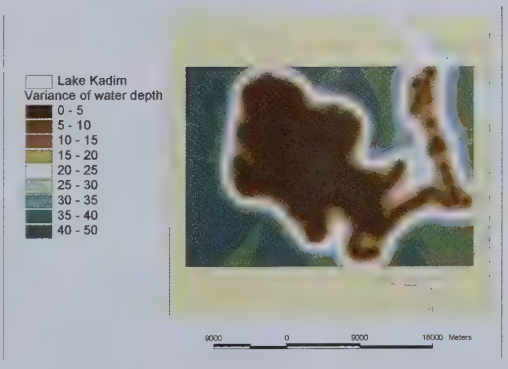


FIGURE C.19
Variance of water depth after Kriging



Try now to Krig yourself the other data of the Theme 'Lake Kadim data.shp' (distribution of: adult carp, carp larvae, Secchi depth, watertemp, and clupeid larvae, and concentration of chlorophyll).

FIGURE C.20
Semi variogram made with a 5 metres lag interval

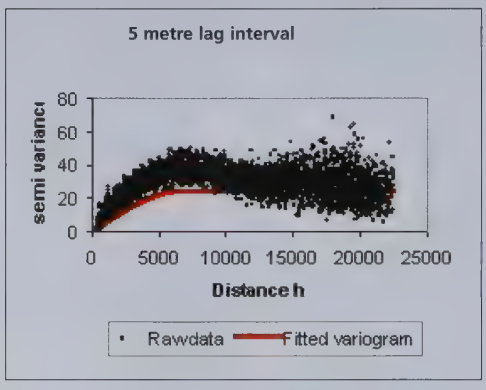
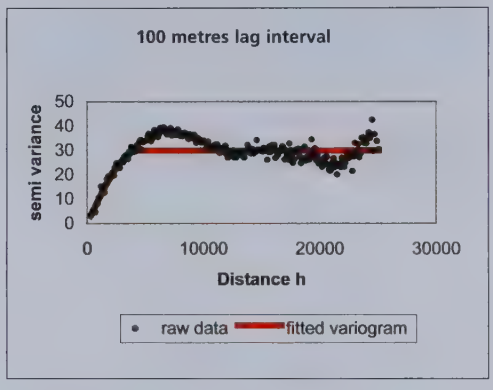


FIGURE C.21
Semi variogrammade with a 100 metres lag interval



This annex is merely an introduction to Kriging. Kriging is a complex procedure that requires greater knowledge about spatial statistics than can be covered in this annex. Before applying Kriging, you should acquire a thorough understanding of the fundamentals of Kriging and have assessed the appropriateness of your data for modelling with this technique. If you would like to learn more about Kriging, some excellent references about Kriging and statistical interpolation are listed below:

- Burrough, P.A. 1986. Principles of Geographic Information Systems for Land Assessment., Oxford University Press, New York.
- Heine, G.W. 1986. A controlled study of some two-dimensional interpolation method. COGS Computer Contributions, 3(2): 60–72.
- McBratney, A.B. & Webster R., 1986. Choosing functions for semi-variograms of soil properties and fitting them to sampling estimates. *Journal of Soil Science*, 37: 617–639.
- Oliver, M.A. 1990. Kriging: a method of interpolation for geographical information systems. *International Journal of Geographic Information Systems*, 4 (4): 313–332.
- Press, W.H., Teukolsky, S.A., Vetterling, W.T. & Flannery, B.P. 1988. *Numerical Recipes in C: The Art of Scientific computing.* New York, Cambridge University Press. 904 pp.
- Royle, A.G., Clausen F.L. & Frederiksen P., 1981. Practical universal Kriging and automatic contouring. *Geoprocessing*, 1: 377–394.

Geographic information systems
in fisheries management and planning

FAO
FISHERIES
TECHNICAL
PAPER

449

© FAO 2003

CD2

Data for exercises

COMPACT
disc
DIGITAL DATA

Geographic information systems
in fisheries management and planning

FAO
FISHERIES
TECHNICAL
PAPER

449

© FAO 2003

CD1

Data for exercises

COMPACT
disc
DIGITAL DATA

The FAO Inland Water Resources and Aquaculture Service (FIRI) has been active in promoting the use of geographic information systems (GIS) and remote sensing since 1985. However, a manual to use along with GIS software for the fisheries biologists in the field, explaining the use of GIS in inland fisheries management in a way that is understandable to non-GIS users, had not been produced by FIRI until now. This manual has been written to overcome this knowledge-gap, as a "do-it-yourself-manual" giving a short introduction to GIS software and its applications in fishery science. The overall objective is to encourage fishery managers to use GIS to foster the sustainable use of natural resources. It is aimed at fisheries biologists, aquatic resource managers and decision-makers in developing countries who have no knowledge about GIS, and will be useful for a broad range of fishery applications. Although the manual by no means covers all the possibilities of GIS, it touches upon some of the most important features for fisheries management and planning.

ISBN 92-5-104999-8 ISSN 0429-9345

9 789251 049990

TC/M/Y4816E/1/12.03/1500